DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

USE OF AGRO INDUSTRY TREATMENT PLANT SLUDGE FOR AGRICULTURAL PURPOSES

by
Tarık Şengün

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İZMİR

USE OF AGRO INDUSTRY TREATMENT PLANT SLUDGE FOR AGRICULTURAL PURPOSES

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Tarık Şengün

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İZMİR

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"USE OF AGRO INDUSTRY TREATMENT PLANT SLUDGE FOR AGRICULTURAL PURPOSES"** completed by **TARIK ŞENGÜN** under supervision of **ASSOC. PROF. DR. DENİZ DÖLGEN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

Land application of sewage sludge is performed in an environmentally safe and cost-effective manner in many communities. Although land application of sewage sludge has become a common practice over the past several decades, the application of sludge generated by industrial plants is limited due to fears of the accumulation of toxic matter in soils and plants. However, the accumulation of heavy metals and their availability to plants depend strongly on the composition of the sludge, the application rate, soil properties, and the crop species. Therefore, agro-industries have considerable potential due to the low heavy metal content and high organic matter content of their sludges.

The main objective of this study was to investigate the land use potential of the agro-industry sludges. In this framework, physico-chemical and biological properties of sludges were investigated. Characterization study stated that sludge generated from agro-industries was deficient in terms of nutrients, but rich in organic matter. In general, heavy metal concentrations detected in the sludge samples were lower than the tolerance limits. However, coliform densities were higher thus improvement of the sludge characteristics in terms of coliform was required. Therefore, in order to improve the microbiologic quality chemical stabilization, thermal stabilization and combination of these methods were performed.

The results were shown that 3% lime dosage was sufficient to keep pH over 12 during 24 hours. Pathogen reduction was affected from the increasing temperatures. Lower temperatures, i.e. 50 and 70 ^{o}C were not enough to reduce the pathogen levels below 1000 MPN/g DS. However, the high temperature thermal stabilization (180 ^{o}C) can fulfill the USEPA Class A Pathogen requirements. Besides, results obtained from high pH-high temperature process indicated that the high pH (> 12) can considerably reduce the heating time required for an effective pathogen reduction.

When the chemically stabilized sludge was heated to a temperature of 70°C, 30 minutes heating time was necessary to fulfill Class A biosolid requirements. For the 180°C (heating temperature), 10 minutes heating time was sufficient to fulfill Class A biosolid requirements.

Key Words: Sewage sludge, biosolids, agricultural use, plant nutrients, soil properties, stabilization

GIDA SANAYİ ARITMA ÇAMURLARININ TARIMSAL AMAÇLI KULLANIM OLANAKLARININ ARAŞTIRILMASI

ÖZ

Atıksu arıtım işlemleri sonucu oluşan arıtma çamurlarının toprağa verilerek bertarafı çevresel açıdan dost ve ekonomiye katkısı bakımından pek çok ülkede üzerinde önemle durulan bertaraf tekniklerinden biridir. Son yıllardaki genel çevreci bir yaklaşımla arıtma çamurlarının tarım alanlarında kullanımı ve değerlendirilmesi etkili bir bertaraf yöntemi olarak yaygın bir kullanım alanı bulmasına rağmen, endüstriyel atıksuların arıtılması sonucu oluşan arıtma çamurları ise içeriğindeki farklı özellikteki ve farklı konsantrasyonlardaki kirleticilerin toprağa ve bitkiye geçmesi gibi olumsuz yönlerinden dolayı kullanımı sınırlandırılmaktadır. Öte yandan, çamurun toprağa uygulanmasıyla ağır metallerin ve diğer kirletici maddelerin bitkiye geçmesi uygulanan çamurun bileşenine, çamur uygulama oranına, çamurun uygulandığı toprağın özelliklerine ve uygulama yapılacak alandaki bitki türü gibi faktörlere bağlıdır. Gıda sanayi atıksularının arıtılması sonucu oluşan arıtma çamurları ise düşük ağır metal seviyesi ve yüksek organik madde içeriğinden dolayı tarımsal amaçlı kullanımı önem arz etmektedir.

Bu çalışmada, gıda sanayi arıtma tesisi atıkları'ndan arıtma çamurunun karakterize eden özellikleri ve tarımsal kullanım olanağı araştırılmıştır. Bu amaçla, öncelikle agro-endüstri alanında faaliyet gösteren işletmelerden çamur örnekleri alınarak makro ve mikro besin maddeleri ve ağır metal analizleri yapılarak çamurun fiziko-kimyasal ve mikrobiyolojik özellikleri belirlenmiştir. Yapılan analizler sonucu agro-endüstri arıtma çamurlarının içeriğinde yüksek miktarlarda organik madde tespit edilmesine rağmen, bitki besin elementinin ise yetersiz olduğu bulunmuştur. Alınan çamur örneklerindeki ağır metal seviyelerini sınır değerlerle karşılaştırarak çamur örneklerindeki ağır metal seviyelerinin belirtilen sınır değerlerin altında olduğu belirlenmiştir. Bununla birlikte, çamur örneklerindeki patajen mikroorganizma sayısı belirtilen sınır değerleri aştığı için çamurun mikrobiyolojik kalitesini iyileştimek amacıyla çamura kimyasal stabilizasyon, ısıl işlem ve kimyasal

stabilizasyon ile ısıl işlemin kombinasyonu olan stabilizasyon işlemleri uygulanmıştır.

Uygulanan stabilizasyon işlemleri sonucu olarak çamurdan patajonlerin giderilmesi için istenen pH - zaman değeri (pH≥ 12 – 24 saat) için önerilecek kireç dozunun %3 olduğu tespit edilmiştir. Çamur örneklerinin mikrobiyolojik kalitesini iyileştirmek için yapılan çalışmalar sırasında çamurdaki patojen mikroorganizmaların sıcaklık artışından etkilendikleri gözlenmiştir. Bu çalışmanın sonucunda çamur örneklerine düşük sıcaklık değerinde (50 ^{o}C ve 70 ^{o}C) ısıl işlem uygulandığında belirlenen patojen mikroorganizma değerinin standart değer olan 1000 MPN/g DS' nin üzerinde olduğu belirlenmiştir. Öte yandan bu değer yüksek sıcaklıktaki (180 ^{o}C) stabilizasyon uygulaması için US EPA standartlarını sağladığı belirlenmiştir. Bunun yanı sıra, çamura kimyasal stabilizasyonun ve ısıl işlemin birlikte uygulanmasıyla çamur örneklerinde istenen pH değerinin (pH> 12) ve özgün sıcaklık değerinin karşılanması nedeni ile çamurun yapısındaki patojenlerin etkili bir şekilde uzaklaştırıldığı tespit edilmiştir. Bu bağlamda, kimyasal olarak stabilize edilmiş çamura, 30 dakika boyunca 70 ^{o}C veya 10 dakika boyunca 180 ^{o}C ısıl işlem uygulanması ile çamurdaki patojen mikroorganizma seviyesinin Class A sınıfı biyokatılar için önerilen sınır değerin altına düştüğü belirlenmiştir.

Anahtar Kelimeler: Arıtma çamuru, biyokatılar, tarımsal kullanım, bitki besin elementi, toprak özellikleri, stabilizasyon

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CHAPTER ONE
INTRODUCTION

As a result of population growth and new legislation to control water pollution, wastewater treatment plants are becoming more advanced and more common in world wide. The objective of wastewater treatment is to produce an effluent that does no harm to, and possibly benefits, the watercourse and the surrounding ecosystem into which it is introduced. The human population is part of this ecosystem, and thus a major objective of wastewater treatment plants is to reduce, or even to eliminate, diseases. Modern treatment plants are reasonably effective at achieving this goal and instances where human wastewater discharges from a poorly-operated treatment plant have caused public health problems increasingly rare (Spinosa; Vesilind, 2001, p. 3-4).

Most wastewater treatment processes produce sludge which has to be disposed of properly. Disposal of this by-product both difficult and expensive, often requiring over 50% of the operatory budget for the wastewater treatment plant (Spinosa; Vesilind, 2001, p. 3-4). There are many methods for disposal of the sludge, such as landfilling, surface disposal, incineration or land application or other beneficial uses. As an alternative to disposal by landfilling or incineration, land application is the most widely used and usually less expensive than alternative methods of disposal (Dolgen et al., 2007).

Land application of sewage sludge has been practiced in many countries for centuries so that the nutrients (e.g., nitrogen, phosphorus) and organic matter in sewage sludge can be beneficially used to grow crops or other vegetation. Besides, over the years, land application has been increasingly managed to protect human health and the environment from various potentially harmful constituents typically found in sewage sludge, such as bacteria, viruses, and other pathogens; metals (e.g., cadmium and lead); toxic organic chemicals (e.g., PCBs); and nutrients (e.g., nitrogen as nitrate). Although land application of sewage sludge has become a common practice over the past several decades, the application of sludge generated by industrial wastewater treatment plants is limited. This may be due to fears of the

accumulation of toxic matter in soils and plants. However, the accumulation of heavy metals and their availability to plants depend strongly on the composition of the sludge, the application rate, soil properties, and the crop species. Therefore, certain industries such as food (vegetable) processing, the tobacco industry, pulp and paper production, fermentation industries, beverage, distilleries, and dairy industry have considerable potential due to the low heavy metal content and high organic matter content of their sludges.

The main objective of this study was to investigate the land use potential of the industrial sludges produced from the agro-industry wastewater treatment plants. The aim of this study is addressed by;

- Investigating the quality of sludges from various industries (mainly agro-industries due to their low heavy metal and high organic contents;
- Determining the parameters exceeding the limits given in the regulations;
- Investigating the treatment methods for the improvement of the sludge characteristics to meet the standards for land applications.

In this framework, characterization study was achieved as first. Physical, chemical and biological properties of sludge samples were investigated. Characterization study stated that sludge generated from agro-industry treatment facilities was deficient in terms of plant nutrients especially nitrogen, phosphorus and potassium, but rich in organic matter. Besides, heavy metal concentrations detected in the sludge samples were lower than the tolerance limits. Regarding the bacterial contamination, coliform densities were higher than 10^3 MPN/g DS thus improvement of the sludge characteristics in terms of coliform was required to obtain Class A biosolid. Therefore, in order to improve the microbiologic quality chemical stabilization, thermal stabilization and combination of these methods were performed separately.

This document is structured to provide a general understanding of the land application and its principles, including definitions of sludge and characteristics, parameters influencing land application; and particularly to give an insight for the

environmentally sound management of industrial sludges. Chapter 1 summarizes the initiatives and main goals of this study. Chapter 2 and 3 review the literature; sludge characteristices and treatment methods, principles of land application and the regulatory framework. Chapter 4 explains the experimental studies including characterization and treatability studies. The results obtained from the experiments are discussed in Chapter 5. Finally, Chapter 6 contains both conclusions and the recommendations for further studies.

CHAPTER TWO
SLUDGE TREATMENT AND DISPOSAL

2.1 Definition

Sludge, is the inevitable "waste" product of wastewater treatment plants. As defined by EPA in 40 CFR Part 503, sewage sludge is any "solid, semisolid, or liquid residue generated during the treatment of domestic sewage in a treatment works." Generally, these by-products consist of microorganisms and detrital matter from the treatment process, but they may also include domestic septage, scum, or solids removed in primary, secondary, or advanced wastewater treatment processes, and any material derived from sewage sludge (WEF 1998).

Although, sewage sludge is defined in the Part 503, the term "biosolids" is not used in the Part 503 rule, but EPA (1995) defines biosolids as "the primarily organic solid product yielded by municipal wastewater treatment processes that can be beneficially recycled" as soil amendments. Therefore, biosolids can be defined as the wastewater solids (sewage sludge and residential septage) that have been chemically or biologically treated to produce a nutrient-rich organic material. Only those biosolids that meet strict quality standards for pollutants, pathogens and vector attraction may be land applied for beneficial purposes. All other biosolids must be disposed in a landfill or incinerated.

2.2 Sludge Sources

Preliminary wastewater treatment extracts coarse solids and grit through screens and other filtering devices. These coarse materials are not incorporated in sludge or in biosolids. Primary wastewater treatment usually involves gravity sedimentation of screened wastewater to remove settled solids. Half of the solids suspended in wastewater are removed through primary treatment. The residual material from this process is a concentrated suspension called primary sludge, which will undergo further treatment to become biosolids.

Secondary wastewater treatment is accomplished through a biological process, which removes biodegradable material. This treatment process uses microorganisms to consume dissolved and suspended organic matter, producing carbon dioxide and other by-products. The organic matter also provides nutrients needed to sustain the communities of microorganisms. As the microorganisms feed, their density increases and they settle to the bottom of processing tanks, separated from the clarified water as a concentrated suspension called secondary sludge, biological sludge, waste activated sludge, or trickling filter humus.

Tertiary or advanced treatment is used when extremely high-quality effluent is required. The solid residual collected through tertiary treatment consists mainly of chemicals added to clean the final effluent, which are reclaimed before discharge, and therefore may not be incorporated into biosolids.

The addition of chemicals and various organic and inorganic substances prior to sedimentation may increase the solids capture and reduce the amount of solids lost in the effluent. This chemical addition results in the formation of heavier solids that trap the colloidal solids or convert dissolved solids to settleable solids. The resultant solids are known as chemical sludges. As chemical usage increases, so does the quantity of sludge that must be handled and disposed. Chemical sludges can be very difficult to process; they do not dewater well and contain lower percentages of solids (Spellman, F. R., 2003, p. 609).

Combined primary and secondary solids comprise the majority of material used at municipal wastewater plants for biosolids production. Careful management throughout the entire treatment process allows plant operators to control the solids content, nutrient value and other constituents of biosolids. Figure 2.1 provides an illustration of the wastewater treatment process together with the sludge sources and disposal routes.

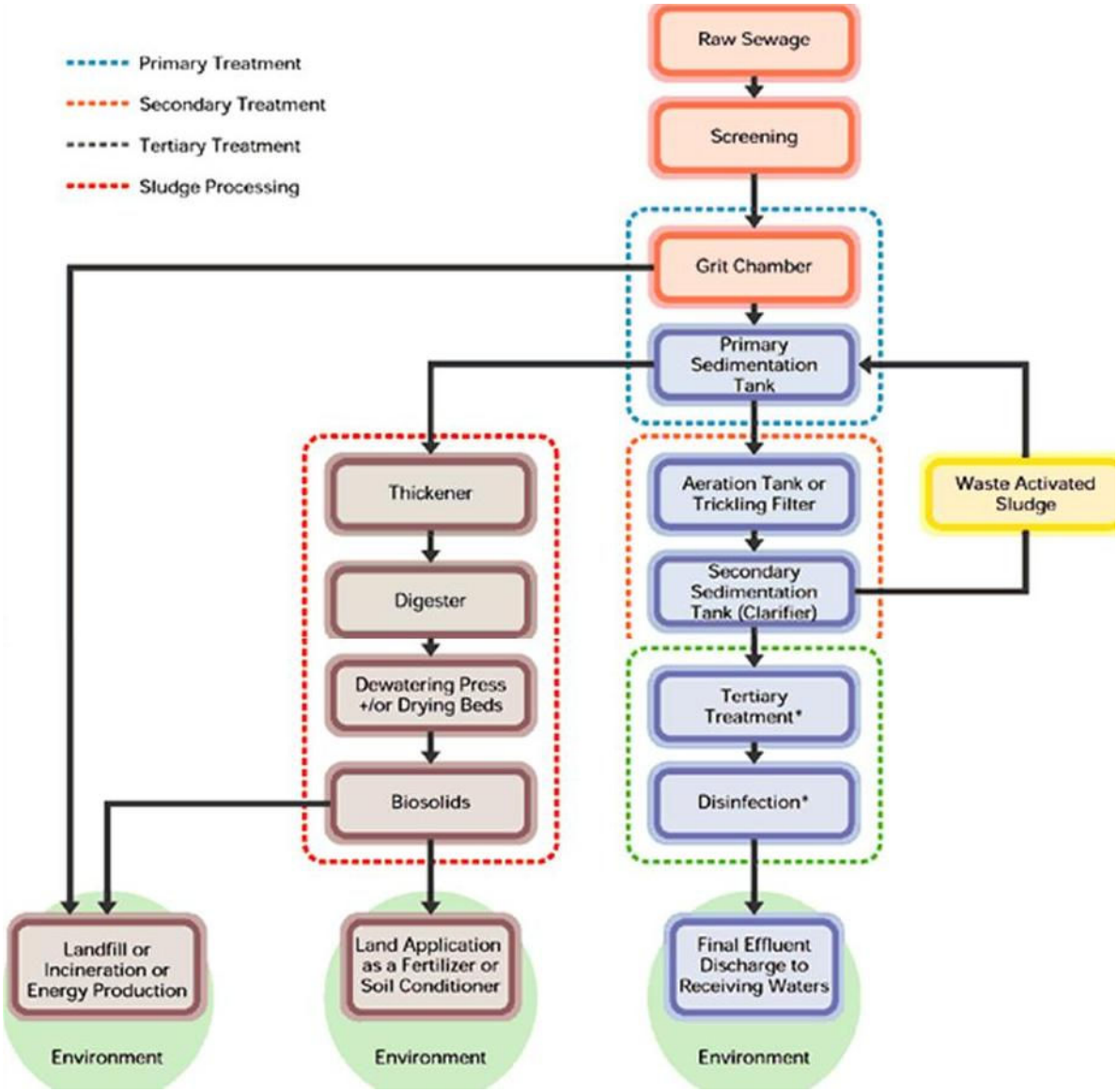

Figure 2.1 Sludge sources and disposal options

2.3 Sludge Characterisation

2.3.1 General Properties of Sludge

Characteristics of sludges play an important role in their use. Various parameters are used for characterization. The parameters are selected according to physical, chemical, and biological features. Table 2.1 shows a survey of parameters and processes. The list is a selection of the most common and interesting parameters, but because of the complex nature sewage sludge, it can not be complete.

Table 2.1 Survey of sludge characterisation parameters (Spinosa and Vesilind, 2001)

Parameter	Explanation	Process
Physical features		
Solid content	Basic parameter-solid conc.	Settlement and disposal
Volatile solid content	Basic parameter-org. solid conc.	Settlement and disposal
Sludge index	Influences clarification and thickening	Settlement
Conditioning	Demand on conditioning agent	Conditioning and dewatering
Particle size	Description of solids	Settlement, conditioning and dewatering
Density	Influences dewatering in centrifuges	Conditioning and dewatering
Rheology/viscosity	Describes pumping processes	Pumping
Chemical features		
pH/alkalinity	Describes the stability of digestion	Stabilization
Fatty acids	Describes the stability of digestion	Stabilization
C, N, P concentration	Concentration of sludge and process water with C, N, P	Disposal
Pollution level	Heavy metals, org. hazardous substances	Disposal (i.e. Agricultural use, landfill)
Biological features		
Pathogenic features	Describes hygienic aspects of sludge	Disposal (agricultural use)
Biological stability	Describes the biogas production	Disposal (agricultural use, landfill)
Bulking	Influences clarification and thickening	Settlement properties

In general, physical properties affect the method of application, as well as the soil's physical and chemical properties. They may affect the availability and accumulation of plant nutrients and trace elements. Chemical properties affect plant growth as well as the soil's chemical and physical properties. Biological properties have an effect on human health and the environment as well as the soil's microbial population, organic matter's decomposition in soil.

2.3.2 Physical Features

The main goal in physical processing is to increase the solid content and to decrease the volume of the sludge by removing water. Dewatering reduces the volume and the quantity of sludge that needs to be disposed of or subsequently treated. The dewatering result can be described by the total solids concentration of the sludge cake and the amount of conditioning agents.

The relative solid and liquid fractions of the slurry are most commonly described by the solids concentration, expressed as mg/l or percent solids. Sludges composed of heavy solids (e.g., lime or iron flocs) may have higher specific gravities; hence the mg/l to percent relationship no longer would be valid. The solids in the sludge equals the sum of dissolved and suspended solids, the latter defined as that fraction that does not pass through filter. Each of these three types of solids (total, dissolved, suspended) can be further subdivided into fixed and volatile, the latter defined as the fraction that oxidizes at 600 ^{o}C (Vesilind P.A., 1979, p.18).

Total solids (TS) include suspended and dissolved solids and are usually expressed as the concentration present in the sludge. TS depend on the type of wastewater process and sludge treatment prior to land application. Typical solids contents of various sludge processes are expressed as 2-12% for slurry, 12-30% for dewatered sludge and 50% for dried or composted sludge.

Volatile solids (VS) provide an estimate of the readily decomposable organic matter in sludge and are usually expressed as a percentage of total solids. VS are an important because of potential odor problems at land application sites. A number of treatment processes, including anaerobic digestion, aerobic digestion, alkaline stabilization, and composting, can be used to reduce VS content and, thus, reduce to potential for odor (G.K. Evanylo, 1999a).

Actually, the solids content of biosolids affects the method of land application. Liquid or low-solids biosolids will generally be injected into the soil to prevent

vectors and provide beter aesthetics. Vector reduction is part of the USEPA 40 CFR 503 Regulations. The addition of liquid biosolids also insreases the moisture content and consequently its benefit in improving soil structure will occur after repeated applications and after a long period of time. The amount of plant nutrients and trace elements depends on the quantity and percent solids of the biosolids.

Dewatered or semisolid biosolids are usually spread on the surface and subsequently plowed into the soil. The concentration of solids adds organic matter to the soil. This added organic matter improves the soil's physical properties, especially soil structure, soil moisture content, and cation exchange capacity. Heat-dried products are generally applied as fertilizers and add little organic matter since small amounts are applied. They do not usually affect the soil's physical properties.

The organic content of biosolids will vary, depending on the solids content and extent of treatment. Organic matter in biosolids can be as high as 70% depending on the wastewater treatment (e.g., digestion, bulking agent addition in the case of compost, lime addition, and addition of ather materials) (Epstein E, 2003, p. 14).

2.3.3 Chemical Features

Chemical properties affect plant growth as well as the soil's chemical and physical properties. pH, soluble salts, plant nutrients, trace elements to humans and animals, and organic chemicals are important chemical characteristics of sludges. On the other hand, chemical properties of sludges are affected by several factors such as wastewater quality (extent of industrial pretreatment), extent of treatment (primary, secondary, or tertiary, chemicals used in treatment, and methods of stabilization (Epstein E., 2003, p. 14).

2.3.3.1 Trace Elements, Heavy Metals, and Micronutrients

Trace elements have been defined as the elements that occur in natural systems in small amounts and that, when present in excessive concentrations, are toxic to living organisms (Kirkham, 1977). The plant-soil system has three protective mechanisms

that can limit these potentially toxic trace elements in the aerial portions of a plant, and so minimize health problems to animals or humans. The "Soil-Plant Barrier," as it is called by Chaney [1980], includes:

i) Elements that are insoluble in soil and do not accumulate in the plant (Pb, Hg, Cr, F, Ag, Au, Ti, Sn, Si, and Zr);

ii) Elements that are absorbed into the root but are insoluble in the root or have limited translocation to the shoot (Fe, Al, and occasionally Hg and Pb);

iii) Elements which when applied in excess cause phytotoxicity, so plants are not consumed by man or domestic animals (Zn, Cu, Ni, Co, Mn, As, and B).

Not all trace elements present in municipal sewage sludges fall into one of these three categories. Important exceptions are Cd, Se, and Mo which can cause toxicities in animals and humans. Molybdenum and Se are present in sewage sludges in low concentrations, thus these elements normally do not limit the rate of sludge application to soil. Cadmium, however, has caused adverse health effects in humans who ingested plants grown on soils contaminated with high levels of Cd [Chaney, 1980]. Ingestion of soil or a sludge-soil mixture by grazing animals provides a direct pathway to adding excessive trace elements (especially Pb) to the food chain [Chaney, 1980]. The Council for Agricultural Science and Technology (CAST, 1976) classified Cd, Cu, Mo, Ni, and Zn as potential hazards in land application of municipal sewage sludges. These metals tend to accumulate in plants and cause either reduced yields or health problems to animals or humans that ingest the plants.

2.3.3.2 Organic Chemicals

Sewage sludge may also contain synthetic organic chemicals from industrial wastes, household products, and pesticides. Although, most sewage sludge contains low levels of these chemicals and does not pose a significant human health or environmental threat, it should be carefully controlled especially in disposal.

Organic chemicals may be volatilized, degraded (through biotic and/or abiotic processes), sorbed to sludge, or discharged in the aqueous effluent. Degradation

results in the creation of breakdown products that can be either more or less toxic than the original compound.

For many hydrophobic organic chemicals, sorption to the sewage sludge solids is the primary pathway for their removal from wastewater. This is especially true of persistent, bioaccumulative toxics that may enter the waste stream (Petrasek et al., 1983). Even volatile chemicals, such as benzene, are commonly found in sewage sludges as a result of sorption to organic substances in the sludge (Wild et al., 1992).

2.3.3.3 pH

pH of most biosolids whether liquid, semisolid, or solid is generally in range of 7 to 8, unless lime is added during the wastewater treatment process. Lime, kiln dust and other alkaline products may be added to increase the pH and achieve the USEPA pathogen requirements (Epstein E., 2003, p. 22-23). Digested sludge or sludge in methanegous phase shows slightly alkaline pH value (7.0-7.5) while primary sludge or sludge in the acetonegous phase has a slightly acid pH value (6.0). Sludge pH is therefore, a good indicator of digestion conditions, as long as there is no industrial contamination (Spinosa and Vesilind, 2001).

2.3.3.4 Plant Nutrients

Sewage sludge contains nutrients which favour its agricultural use. The major plant nutrients are nitrogen (N), phosphorus (P) and potassium (K). Other macronutrients are calcium (Ca), magnesium (Mg), and iron (Fe). Sewage sludges contain significant amounts of nitrogen and phosphorus but only small amounts of potassium. Table 2.2 shows fertilizing values of 6000 analysed sewage sludges.

Table 2.2 Survey on nutrients in sewage sludges (Spinosa and Vesilind, 2001)

Parameter	Unit	Value		
		Ave.	Min.	Max.
N	g/kg SS	38.4	0.1	246
P_2O_5	g/kg SS	36.5	0.2	344
K_2O	g/kg SS	4.2	0.1	95
MgO	g/kg SS	9.7	0.1	122
CaO	g/kg SS	73.7	0.1	727
SS	%	12	0.1	100

Average concentrations of certain macronutrients in various types of sludges are also presented in Table 2.3. The data classified as “other” in the Table 2.3 underlines the data gathered from lagoons, primary, tertiary, and unspecified biosolids. These data do not reflect the use of alkaline products, which would increase the Ca and Mg content. Furthermore, during that period, ferric chloride and lime were used in dewatering, which was principally done by vacuum filters. Today belt fitler presses and centrifuges predominate and use polymers. Consequently the concentration of Fe, Ca, and Mg would probably be lower (Epstein E., 2003, p. 23-24).

Table 2.3 Median concentration of several macronutrients (Sommers, 1997)

Nutrient	Type of Biosolid			
	Anaerobic	Aerobic	Other	All Biosolids
% N	4.2	4.8	1.8	3.3
% P	3.0	2.7	1.0	2.3
% K	0.3	0.4	0.2	0.3
% Ca	4.9	3.0	3.4	3.9
% Mg	0.5	0.4	0.4	0.4
% Fe	1.2	1.0	0.1	1.1

2.3.4 Biological Features

Sewage sludge can vary in the quality and quantity of its organic and inorganic content, including the types and numbers of pathogens it contains. The nature and concentrations of pathogens in sewage will depend on the health and the size of the population in the catchment. In a large community a small proportion of the population is likely to be infected at any time, and consequently low levels of pathogens will be in the sewage at all times. In a small community, the excreta of a few people who may or may not be infected, represents a large part of the sewage input and in these circumstances the sewage will contain either no pathogens or relatively high concentrations.

Pathogens that are excreted by the respiratory route are unlikely to be present in sewage sludge in large numbers although some respiratory viruses are excreted with faeces. Table 2.4 shows that the pathogenic micro-organisms that may be found in sludge derived from faecal material. Bacteria are capable of independent existence and can multiply wherever suitable conditions are present. Most are inactivated at temperatures in excess of 70 ^{o}C over a relatively short period of time. Lower temperatures over longer time periods are equally effective. However, some that produce spores, e.g. Clostridium species, require higher temperatures for complete kill.

In sewage sludge and similar wastes, most of the pathogens will be in hazard category 2 (Environment DG, 2001), but a few, Salmonella typhi, E. coli and some mycobacteria, for example, have a higher rating of category 3. The dangerous properties of some pathogens arise from their ability to produce stable exotoxins e.g. Clostridium botulinum. Advanced and conventional sludge treatment systems produce a stabilised final product where such organisms are unlikely to multiply to large numbers and there are unlikely to be problems arising from bacterial toxins during sludge storage or application.

Table 2.4 Pathogenic micro-organisms that may be found in sludge derived from faecal material

Bacteria	**Protozoa**
Salmonella spp.	Entamoeba histolytica
Shigella spp.	Giardia lambia
Escherichia coli	Toxoplasma gondii
Pseudomonas aeruginosa	Sarcocystis
Yersinia enterolitica	**Helminths**
Clostridium perfringens	Taenia saginata
Clostridium botulinum	Taenia solium
Bacillus anthracis	Diphyllobothrium latum
Listeria monocytogenes	Echinococcus gramulosus
Vibrio cholera	Ascaris lumbricoides
Mycobacterium spp.	Ancylostoma düodenale
Leptospira spp.	Toxocara canis
Campylobacter spp.	Toxocara cati
Staphylococcus	Trichuris trichura
Streptococcus	
Viruses	**Yeast**
Poliovirus	Candida albicans
Echovirus	Candida krusi
'New' enterovirus	Candida tropicalis
Adenovirüs	Candida tropicalis
Reovirus	Candida guillermondii
Hepatitis A-virus	Cryptococcus neoformans
Rotavirus	Trichosporon
Astrovirus	**Fungi**
Coronavirus	Calicivirus Aspergillus spp.
Norwalk-like calicivirus	Aspergillus fumigatus
Small round viruses	Phialophora richardsii
Parvovirus	Geotrichum candidum
Adenoassociated viruses	Trichophton spp.
Influenza virus	Epidermophyton spp.

Primary sludge has a mixed taxonomy (classification of organisms) and may contain all pathogenic organisims and worm eggs existent in human and animal faeces. Therefore, this type of sludge must be considered to be a possible health hazard. Activated sludge also contains pathogenic organisms, as demonstrated by Van Gilss (1964). Anaerobic digestion reduces the number of, but does not totaly destroy, pathogenic organisms. Pathogens which survive normal digestion times of 30 days are *Salmonella typhosa* (McKinney et al., 1958), *Entamoeba histolitica, Ascaris eggs* and *helminth cysts* (Peterson et al., 1973; McWhorter, 1974). Most enteric (pathogenic) viruses are inactivated during digestion, but positive coliphage tests indicate the strong possibly of the persistence of enteric viruses in digested sludge (Malina et al., 1975). During digestion, pathogenic germs and worm eggs can not breed or grow because they are weakened or killed depeding on digestion time and temperature. When sludge is composted according to the rules it is almost disinfected due to temperature and microbial competition. Complete disinfection can only be achieved by pasteurisation at more 70 ^{o}C or by drying the sludge.

Table 2.5 presents typical pathogen concentrations in various sludges. Coliforms are of course normally not pathogenic but are indicators of pathogens. Similarly, enteric viruses are estimated based on plaque-forming units (PFU) which are actually colipathogens (viruses that attack coliforms) but are themselves not pathogenic to humans (Hanson, 1972).

Table 2.5 Concentrations of pathogens in sludge (Vesilind P. A., 1979)

Sludge	**Virus (PFU/100 ml)**	**Coliform (10^6/ml)**	**Salmonella (per 100 ml)**	**Pseudomonas (per 100 ml)**
Raw Primary S.	7.9	11.0-11.4	460	46000
Activated S.	-	2-2.8	74-23,00	1100-24000
Trickling Filter S.	-	11.5	93	11000
Mixed Digested S.	0.85	0.4	29	34
Reference	Palfi (1973)	Farrell (1974)	Farrell (1974)	Farrell (1974)

2.4 Sludge Treatment

Sludge must undergo various types of processing for economic and hygienic reasons. The purpose of all types of sludge processing is to reduce the volume, stabilize the sludge, remove water and kill pathogenic organisms. It is processed in stages that comprise a sequence of treatments such as conditioning, thickening, dewatering and stabilization (European Commission, 2001, p. 37). Table 2.6 lists several types of sludge treatment processes, the effect each treatment has on biosolids and how that treatment may affect the application of biosolids to land (USEPA, 1995).

Table 2.6 Effects of biosolids treatment processes on land application practices (partially adapted from USEPA, 1995a)

Treatment processes and definition	**Effect of process on biosolids**	**Effect of process when utilizing biosolids for land application**
Thickening: Low-force separation of water and solids by gravity, flotation or centrifugation.	Increases solids content by removing water	Lowers transportation costs
Digestion (aerobic/anaerobic): Biological stabilization through conversion of organic matter to carbon dioxide, water and methane.	Reduces the biodegradable content (stabilization) by. conversion to soluble materials Reduces potential odor.	Reduces biosolids quantity andtransportation costs. Reduces pathogen vector attraction duringlevels and odor. application.
Alkaline stabilization: Stabilization through the addition of alkaline materials, such as hydrated lime.	Raises pH. Temporarily decreases biological activity. Reduces pathogen levels and biosolids can have liming value controls putrescibility and odor.	Reduces the nitrogen value biosolids. Lime-stabilized biosolids can have liming value and substitute for ag lime.
Conditioning: Processes that cause biosolids to coagulate to aid in the separation of water.	Improves sludges' dewatering characteristic. May increase dry solids mass and improve stabilization.	Treating biosolids with polymers may require special operational considerations at application sites.
Dewatering: High-force separation of water and solids. Methods include vacuum filters, centrifuges, filter and belt presses, etc.	Increases solids concentration to 15 to 45 percent. Lowers nitrogen and potassium concentrations. Improves ease of handling.	May reduce nutrient value and land requirements. Lowers transportation costs.
Composting: Aerobic, thermophilic, biological stabilization in a windrow aerated static pile or vessel.	Lowers biological activity, destroys pathogens and converts sludge to humuslike material.	Material has excellent soil conditioning properties. Contains less plant-available nitrogen than other types of biosolids. Increases transportation costs.
Heat drying: Use of heat to kill pathogens and eliminate most of the water content.	Disinfects sludges, destroys most pathogens, and lowers odor and biological activity.	Greatly reduces biosolids volume, May reduce the nitrogen value of biosolids.

2.4.1 Thickening

The sludge produced at the wastewater treatment plant contains lots of water and it has to be thickened in order to reduce the volume and cost for the following treatments. The thickening methods vary with the nature of the sludge and the purpose is to remove some of its free water. *Flotation* may be a suitable method for chemical and biological sludge while primary sludge is best thickened by various *sedimentation processes*. C*entrifugation* can be used either for thickening or dewatering purposes (European Commission, 2001, p. 38-39).

2.4.2 Conditioning

Conditioning of the sludge involves modification of the sludge structure so that more water can be separated. This will improve further treatments such as thickening or dewatering and it may also restrict the fine particle content of the reject water. *Chemical conditioning* uses mineral agents such as lime or salts or an organic compound, which are different kinds of polymers. Another way is *thermal conditioning* where sludge is heated to 150-200 ºC in 30 to 60 minutes. Heating to 40 ºC or 50 ºC is also possible and will give a partial thermal conditioning (European Commission, 2001, p. 38).

2.4.3 Stabilization

Raw sludge is biologically active since it contains biodegradable compounds. The decomposition rate has to be increased in order to avoid odour problems due to anaerobic degradation. Stabilization is of importance in regard to hygienization since the odors are reduced and therefore do not attract vectors via smell. This can prohibit re-infection and re-growth of pathogens. After stabilization, the volume has decreased, hygienization has occurred and the sludge is no longer regarded as active.

Anaerobic digestion is a stabilization method that will reduce the volume and stabilize the sludge. It will also give a partial hygienization. The total quantity of the

sludge is reduced by about 35% (European Commission, 2001, p. 42). The decomposition process in a digester has several stages. Carbohydrates, fats and proteins are broken down in different steps and finally converted into methane gas and carbon dioxide (Metcalf & Eddy, 2003, p. 1506). The produced biogas may be utilized as electricity on the plant or used elsewhere. The temperature is normally kept around 35 °C and the retention time should be more than 20 days in order to receive a good stabilization and hygienization but other retention times and temperatures also exists. Pathogens are reduced during digestion and to which extent depends on the temperature and retention times used (European Commission, 2001, p. 42).

Aerobic digestion is a process where the sludge is placed in an aerated vessel. The decomposition is performed by aerobic microorganisms and this generates heat. If the process is working adequately, more than 70 °C can be reached. Usually the sludge is subjected to 50 to 65 °C for 5 to 6 days and most of the harmful organisms are destroyed. One drawback is that the energy costs are 5 to 10 times higher than for anaerobic digestion (European Commission, 2001, p. 43).

Pasteurization is a method where the sludge is heated to a temperature of 70°C to 80°C for a short period of time (about 30 minutes). This must be done in many countries before the sludge can be spread or deposited in a landfill. The amount of pathogens is reduced during pasteurization (European Commission, 2001, p. 44) but afterwards the sludge must undergo a secondary process in order to stabilize the sludge. The sludge is sensitive to re-infection directly after pasteurization. Therefore, pasteurization is often followed by anaerobic digestion (Spinosa; Vesilind, 2001, p. 367-368).

Thermal drying of the sludge will result in the elimination of interstitial water and reduction of the volume. The process also allows stabilization and hygienization when the dry solids content exceeds 90%. Heat is transferred directly or indirectly to the sludge. At direct transfer, hot gas is used and two important methods are the rotating drum dryer and the fluidized bed dryer. At indirect transfer, a heat transfer

surface is used and the heat is transferred via heat conduction. The drying takes place at different temperatures and if higher temperatures are used (above 300 °C) it is important to control that no dioxins or furan compounds have been formed. A dry matter content of 35 to 90% is reached and re-growth of pathogens is inhibited mainly due to the reduced water content (European Commission, 2001, p. 41).

Composting is another method for managing sewage sludge wherein the organic components of the sludge are biologically decomposed under controlled conditions to a state where the resulting material can be handled, stored or applied to land without adversely affecting the environment. This process is an aerobic process and the microorganisms are mainly mesophilic bacteria (growing at 25-45 °C) and thermophilic bacteria (growing at temperatures above 45 °C) (Spinosa; Vesilind, p. 259-261). The sludge should be mixed with a biodegradable material such as sawdust or animal manure. The moisture content in the compost should be around 50 to 60% in order to keep the microbial activity at its optimum. It is also important to have the right ratio between carbon and nitrogen. The optimum ratio is about 25-30:1 (C:N) (European Commission, 2001, p. 43).

Lime stabilization takes advantage of the fact that all biological activity is effectively terminated when the pH rises above 12. Enough lime, about 30% of the dry solid content, has to be added in order to ensure that no fermentation takes place in the long run. Pathogenic microorganisms are killed effectively during liming, the content of dry solids increases (European Commission, 2001, p. 43).

2.4.4 Dewatering

Dewatering reduces the volume of the sludge via water separation. Raw sludge contains high amounts of water, usually more than 95% by weight. It is only possible to remove a certain proportion of free, adhered and capillary water with the technology available today. Different dewatering processes are *drying beds, centrifuging, filter belt* and *filter press*. All processes except drying beds requires the addition of a chemical conditioning agent. The water content of the sludge after

dewatering depends on the treatment and can reach about 30% (European Commission, 2001, p. 39-40).

2.5 Sludge Disposal

There are several disposal methods for sewage sludge. Changes in public perception and legislation of worldwide are likely to make disposal to landfill less popular. In many countries for regarding to sustainable activities, agricultural use of sludge is becoming more attractive. Incineration is another option for sludge disposal whereas the end product is not suitable for beneficial use.

2.5.1 Landfill

Landfill disposal offers the simplest solution to biosolids handling by concentrating the material in a single location. The risk of release of biosolids-borne pollutants and pathogens is minimal if the landfill is properly constructed and maintained. Economically, the cost compares favorably with other options

Landfill disposal is not, however, without risks. Buried organic wastes undergo anaerobic decomposition which produces methane gas. Methane is a greenhouse gas whose release to the atmosphere has been implicated in possible global warming. This gas is collected at some landfills and the energy content is utilized. The chemicals and nutrients can pose risk to local groundwater from older landfills that do not have synthetic liners or from a liner in a newer landfill developing a leak. There is also a risk for spreading of pathogens when depositing the sludge if the sludge is not sanitized in previous treatment. In addition, the potential benefits of the organic matter and plant nutrients in the biosolids are lost with landfilling (G.K. Evanylo, 1999a; European Commission, 2001, p. 54-55).

2.5.2 Incineration

Incineration is the burning of biosolids at high temperatures in an enclosed device. It reduces the biosolids volume, kills pathogens and destroys most organic chemicals, but it requires energy and safe disposal of the resulting ash. The remaining ash is a stable, inorganic material containing 10 to 20 percent of the original solids. A problem with this method is that it does not destroy trace elements but rather concentrates them in the ash — levels in ash are five to 10 times the original levels. In addition, the ash still requires disposal in landfills. Incineration also produces carbon dioxide, a greenhouse gas, whose release to the atmosphere has been implicated in possible global warming, and the potential benefits of organic matter and plant nutrient recycling are lost. This option is one of the most expensive methods for dealing with biosolids because it requires sophisticated systems to remove fine particulate matter (fly ash) and volatile pollutants from stack gases. The 40 Code of Federal Regulations (CFR), Part 503, titled "Standards for the Use and Disposal of Sewage Sludge" (or Part 503) risk assessment, indicates that incineration clearly carries the greatest health risk because of the release of volatile trace elements into the atmosphere uses (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 5).

2.5.3 Land Application

Biosolid is land applied to improve the structure of the soil and as a fertilizer to supply nutrients to crops and other vegetation grown in the soil. It is commonly applied to agricultural land, forests, reclamation sites, public contact sites (e.g., parks, turf farms, highway median strips, and golf courses), lawns, and home gardens (US EPA, 1994, p. 2). The application of organic matter from biosolids can improve the physical, chemical and biological properties of the soil. Organic matter can increase water infiltration and reduce soil erosion, increase water-holding capacity, reduce soil compaction and increase soil granulation, increase the ability of soil or surface material to retain nutrients, provide nutrients for plant growth, and provide food and energy for beneficial soil microorganisms. Land application is usually less expensive than alternative methods of biosolids management. All of these beneficial

properties make biosolids a good choice for homeowners, landscapers, farmers and foresters. In addition, farmers can benefit from biosolids application by reducing their fertilizer cost.

Agricultural use is subject to great variability over time, however, depending on weather conditions and crop type. Scheduling biosolids transport and application that are compatible with agricultural planting, harvesting and possible adverse climatic conditions requires careful management. When land is not available because of crop growth or because the soil is frozen or wet, some backup contingencies are needed, such as storage or an alternative management option such as landfilling or incineration.

One type of biosolids that is becoming more common recently is dried and/or pelletized biosolids. Because producing biosolids in this form is complex and expensive, dried biosolids are often blended with other materials and marketed as an organic-based fertilizer with balanced nutrient levels. Alkaline stabilization has been used to also produce a nearly odorless and granular product for use as an organic soil conditioner and fertilizer. It can also substitute for agricultural lime uses (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 5-6)

2.5.4 Surface Disposal

In surface disposal, biosolids are placed on an area of land (site) for final disposal. These areas may be monofills, lagoons, waste piles, surface impoundments or dedicated disposal sites uses (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 5).

2.5.5 Other Beneficial Uses

Methane gas is generated during the anaerobic digestion process and has considerable value for heating and electricity. Thermal conversion of sludges to liquid fuel has been proven at a pilot-scale level, where studies have shown that 50 percent of the energy in sludges can be recovered as liquid oil that is storable and

transportable. Sludge ash from incineration has been utilized in construction material and shown to have little environmental risk.

Brown and Chaney (2000) and Chaney et al. (2001) recently summarized how biosolids and other by-products can be combined to make “tailor-made” biosolid mixtures for reclaiming disturbed lands, metal-contaminated soils, and urban and brownfield sites. These types of remediations involve an alteration of soil chemistry, particularly the adsorption of heavy metals by minerals present in biosolids and the decreased availability of these metals to plants. In addition, the organic matter from biosolids provides a substrate for soil microbial communities in these surface materials, which contributes to establishing nutrient cycling for plant growth uses (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 6).

CHAPTER THREE
LAND APPLICATION OF WASTEWATER SLUDGES

3.1 Definition of Land Application

Land application is the practice of applying sewage sludge or biosolids to land for agricultural purposes. Sewage sludge is commonly applied to agricultural land (including pasture and range land), forests, reclamation sites, public contact sites (e.g., parks, turf farms, highway median strips, and golf courses), lawns, and home gardens. Sewage sludge is land applied in bulk form or sold or given away in a bag or similar container for application to the land. The term bulk implies sewage sludge that is applied generally in large quantities to large parcels of land. Bulk sewage sludge is typically used by commercial and municipal appliers for agriculture, tree and turf farms, golf courses, parks, and reclamation of construction or surface mining sites. Sewage sludge sold or given away in a bag or other container is generally used by the smaller scale user, such as a home gardener or landscaper. Surface disposal is another regulated use or disposal practice for sewage sludge that is similar to land application in that it entails the placement of sewage sludge on the land. The main difference between the two is that in the case of surface disposal, sewage sludge is placed on the land for the purpose of final disposal**,** without regard for the soil enhancing qualities of the sewage sludge.

Recycling biosolids through land application serves several purposes. It improves soil properties, such as texture and water holding capacity, which make conditions more favorable for root growth and increases the drought tolerance of vegetation. Biosolids application also supplies nutrients essential for plant growth, including nitrogen and phosphorous, as well as some essential micro nutrients such as nickel, zinc, and copper. Biosolids can also serve as an alternative or substitute for expensive chemical fertilizers. The nutrients in the biosolids offer several advantages over those in inorganic fertilizers because they are organic and are released slowly to growing plants. These organic forms of nutrients are less water soluble and, therefore, less likely to leach into groundwater or run off into surface waters.

Although the organic nature of biosolids, along with plant nutrients and several trace elements makes it a valuable resource for land application, high concentrations of several trace elements, toxic organic compounds, and pathogens can preclude the beneficial use of biosolids (Epstein E., 2003, p. 1-2). Therefore, the recycling to agricultural land must be controlled in order as to obtain agricultural benefit from the sludge whilst protecting human and animal health and the environment at large.

3.2 Advantages and Disadvantages of Land Application

Land application offers several advantages as well as some disadvantages that must be considered before selecting this option for managing biosolids.

3.2.1 Advantages

Land application is an excellent way to recycle wastewater solids as long as the material is quality controlled. Sewage sludge contains several plant macro nutrients, principally N and P, and in most cases, varying amounts of micronutrients such as boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). Land application returns these valuable nutrients to the soil and enhances conditions for vegetative growth. The exact ratio of these nutrients will not be that of a well-balanced formulated fertilizer; but the nutrients in sewage sludge can be combined with nutrients from other fertilizers to provide the proper amounts of nutrients needed for crop production.

Sewage sludge can also be a valuable soil conditioner. The addition of organic materials like sewage sludge to a fine-textured clay soil can help make the soil more friable and can increase the amount of pore space available for root growth and the entry of water and air into the soil. In coarse-textured sandy soils, organic residues like sewage sludge can increase the water holding capacity of the soil and provide chemical sites for nutrient exchange and adsorption.

The treatment works generating the sludge can benefit because in many cases agricultural land application is less expensive than alternative methods of sludge use or disposal. The general public may benefit from cost savings resulting from agricultural land application of sludge, and the recycling of nutrients is attractive to citizens concerned with the environment and resource conservation. A major advantage of agricultural land application is that usually the treatment works does not have to purchase land. The land utilized for sewage sludge application is kept in production, its value for future uses is not impaired, and it remains on the tax rolls.

Finally, agricultural land application usually takes place in a relatively rural setting where the application of sludge is similar to conventional farming operations, such as spreading animal manure, and is not likely to become a public nuisance if properly managed.

3.2.2 Disadvantages

Although land application requires relatively less capital, the process can be labor intensive. Even if contractors are used for application, management oversight is essential for program success. Land application is also limited to certain times of the year, especially in colder climates. Biosolids should not be applied to frozen or snow covered grounds, while farm fields are sometimes not accessible during the growing season. Therefore, it is often necessary to provide a storage capacity in conjunction with land application programs. Even when the timing is right (for example, prior to crop planting in agricultural applications) weather can interfere with the application. Spring rains can make it impossible to get application equipment into farm fields, making it necessary to store biosolids until weather conditions improve.

Another disadvantage of land application is potential public opposition, which is encountered most often when the beneficial use site is close to residential areas. One of the primary reasons for public concern is odor. In worst case situations, municipalities or counties may pass ordinances which ban or restrict the use of biosolids. However, many successful programs have gained public support through

effective communications, an absolutely essential component in the beneficial use of biosolids.

Sewage sludge contains not only nutrients and organic matter but also contaminants such as metals and synthetic organics discharged into the sewers from industries and businesses and leached from pipes. Because most heavy metals remain in the soil for a very long time, any additions should be considered permanent additions to the total quantity in the soil. Additionally, sludge also contains high levels of pathogens, which can be reduced or eliminated through sludge treatment.

3.3 Factors Influencing Land Application

Plant nutrients and organic matter are useful to plants and soils, but some of the metals and other constituents that may be present in biosolids are potentially harmful if not managed correctly. Concerns include parasites and pathogens, heavy metals and non-essential trace elements, organic contaminants, salts and nutrients. Public acceptability is another important issue in land application (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 8).

3.3.1 Pathogens

Pathogens are disease-causing microorganisms that include bacteria, viruses, protozoa, and parasitic worms. The list of the some pathogens that can be found in untreated sewage sludge and the human diseases they cause is presented in Table 3.1 (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 8). Pathogens can present a public health hazard if they are transferred to food crops grown on land to which biosolids are applied; contained in runoff to surface waters from land application sites; or transported away from the site by vectors such as insects, rodents, and birds.

Table 3.1 Principal pathogens of concern usually found in domestic sewage sludge (adapted USEPA, 1999a)

Organism	**Disease/symptoms**
Protozoa	
Entamoeba histolytica	Acute enteritis
Balantidium coli	Diarrhea and dysentery
Bacteria	
Salmonella spp.	Salmonellosis (food poisoning), typhoid
Shigella spp.	Bacillary dysentery
Vibrio cholerae	Cholera
Escherichia coli	Gastroenteritis
Viruses	
Hepatitis A virus	Infectious hepatitis
Rotaviruses	Acute gastroenteritis with severe diarrhea
Helminth (parasites)	
Ascaris lumbricoides (roundworm)	Digestive and nutritional disturbance
Trichuris trichiura (whipworm)	Abdominal pain, anemia, diarrhea, etc.
Taenia saginata (tapeworm)	Insomnia, anorexia, nervousness, etc.

Even though biosolids must undergo a pathogen reduction treatment before being applied to land, health hazards associated with pathogens are still a valid concern. Protozoa, bacteria, viruses and parasitic worms may be present in biosolids. Some of these pathogens will die as soon as biosolids are applied to the soil (e.g., *Salmonella* spp.), but some of them can persist longer in the soil (e.g., *Mycobacterium* spp.). During a period of constraint a number of factors will enhance or retard the decay of microorganisms. In reviewing the microbiological hazards of land spreading of wastes Carrington (1997) has drawn together data from a number of sources, which is summarized in Table 3.2. A major disadvantage of determining and applying periods of constraint is that most of the lethal factors can not be controlled or predicted with certainty, e.g. temperature, and duration and intensity of sunlight.

Constraints on land use after sludge application will depend upon the level of sludge treatment, and the nature of the crop or the use of the land. In most instances “advanced” treated sludge can be used with few restrictions but “conventional” treated sludge must be distanced from the harvested material by time, and where crop maturation is a short period, by incorporating the sludge into the soil. Workers

treating, transporting or spreading sludge must receive adequate training and briefing on the risks and precautions to be observed.

Table 3.2 Factors influencing the survival of pathogens in wastes spread on

Factor	Effect
Microbial structure	
Bacteria	**Spore forming bacteria (e.g. *Clostridium spp*.) are more resistant to effects of environmental pressures than vegetative bacteria (e.g. *Salmonella spp*.)**
Virus	**Non-enveloped viruses (e.g. enteroviruses) are more resistant top H change and dehydration than enveloped viruses.**
Parasites	**Most helminths and parasitic protozoa have developed a lifecycle stage, that is resistant to environmental pressures.**
Environmental factors	
Sunlight	**All organisms are sensitive to ultraviolet irradiation at 265nm.**
Temperature	**Survival times are longer at cooler, (but above freezing) temperatures. Enteric bacteria may multiply at summer temperatures.**
Moisture	**Most organisms are not resistant to desiccation. Rainfall may reduce concentrations thrugh runoff or leaching.**
pH	**Survival times are generally shorter at low (<4) or high (>10) pH values.**
Quality of waste	
Pathogen levels	**Die-off usually follows a logarithmic curve, higher concentrations give longer ultimate survival times.**
Organic content	**Suitable organic content will allow the growth of enteric bacteria, if other conditions are satisfactory. However, it will also allow growth of indigenous organisms, or ones migrating from adjacent soil, that are more likely to be adapted to ambient conditions and more succesfully compate for nutrients, oxygen and space.**
Competing organisms	**Waste and/or adjacent soil will support protozoa and nematodes, which are pretadors to bacteria and viruses.**
Toxic substances antimicrobials	**These are unlikely to be present in wastes in effective concentrations. Naturally occuring anti-microbials may be present in adjacent soils.**
Sludge spreading	
Application rate	**Penetration of ultraviolet irradation, heat, moisture and predators from soil are rudeced as the thickness of the sludge blanket increases, as is the loss of moisture by evaporation.**

3.3.2 Heavy Metals and Trace Elements

Depending on the concentration in the soils, some heavy metals can be toxic to plant species, and some potentially toxic elements may occur at increased levels in the food chain (Lee & Delina, 2001). The two concerns regarding trace element additions to soils are that a metal/trace element might (i) become toxic to crops and/or (ii) become sufficiently concentrated in an edible crop to have harmful effects on an animal or human that consumes that crop.

The trace elements (also referred to as pollutants) in biosolids that are of greatest concern are arsenic, cadmium, copper, mercury, molybdenum, nickel, selenium and zinc. In fact, many of these elements are essential nutrients for plant and animal health. These metals pose relatively little hazard to crop production or plant accumulation, because all of them either have low solubility in well aerated soil where field crops are typically grown (i.e, pH 6.0 to 7.5) or are present in biosolids in such small quantities that their addition to soils will be negligible. For instance, lead is of somewhat lesser concern because of insolubility and lower bioavailability, unless it's directly ingested. Other metals normally present in biosolids are manganese, iron, aluminum and chromium, as well as a few others less frequently encountered. Except for cadmium, these elements are not usually taken up by plants in amounts harmful to human consumers.

There are several general concerns with metals in sludges:

i) Certain metals may become toxic to crops after repeated applications of sludge. The most likely metals to cause growth problems in crops are copper, zinc, and nickel, partly because they can occur at high concentrations in sludge. Short-term damage to crops from salinity or boron sometimes occurs with heavy applications of certain sludge.

ii) Certain metals are particularly toxic to animals and humans, notably lead, cadmium, and mercury. Other metals of concern for animals and humans are arsenic, selenium, and molybdenum. Copper deficiency in ruminants can result from intake of excessive sulfur and/or molybdenum, which can be present at high concentrations in sludge.

iii) Whereas many elements are not taken up substantially by crops, others such as cadmium, molybdenum, and selenium are taken up and may be a concern for animal and human health. Although lead is not generally taken up by crops through the root system, dust contamination of crops, particularly leafy vegetables, can result in elevated lead levels where soils have accumulated substantial lead.

Most heavy metals remain in the soil for long periods of time, ranging from several decades (e.g., cadmium) to many centuries (e.g., lead). Crops grown on soils treated with sludge containing elevated trace element concentrations show increased concentrations of cadmium, molybdenum, and several other elements for at least several decades following cessation of sludge application. The uptake of heavy metals depends on the soluble equilibrium and exchangeability of an element and, therefore, its concentration in the soil solution. Thus, soil testing before sludge application is recommended to determine background metal levels. Adsorption mechanisms are important in determining the availability of the metal to plants. Different parameters influence the distribution of the compounds in soil. pH is considered as the most important parameter controlling the availability of metals in soils. pH value modification will enhance the precipitation or dissolution of insoluble hydroxides. Increasing soil pH value also raises adsorption onto clay minerals and organic matter. The Table 3.3 presents heavy metals mobility according to pH. A note is attributed to each metal between 1 (the least available) and 5 (the most available) to estimate its mobility (European Commission, 2001, p. 73-74).

Another factor, of importance for describing the fate of metals in soil could be the cation exchange capacity (CEC). CEC indicates the ability of a soil to adsorb cations. This parameter depends on other factors including pH, organic matter content and soil texture. CEC increases with pH value, organic matter and clay content of the soil. Many authors agree that CEC influence the retention of metals in soil, although some publications did not show any clear relation between CEC and bioavailability.

The organic matter content will influence the availability of metals in soils. Its increase will indeed enable the binding of the metals to increase. Therefore, application of compost containing stable organic matter originating from the co-product tends to decrease the mobility of heavy metals in the soil.

Finally, temperature and soil humidity may affect the heavy metals mobility, as well as the structure and the type of the soil (European Commission, 2001, p. 73-74). In addition, heavy metals from land-applied biosolids do not appear to move through the soil profile and essentially remain in the top 30 cm. This mostly reduces the potential for heavy metal move through the soil into ground (Mantovi, Baldoni, Toderi, 2005).

Table 3.3 Mobility of metals in soil

	Alkaline, neutral	**Acid**
Cd	2	4
Cu	1	3
Zn	2	4
Hg	1	4
Pb	1	3
Cr	1	3
Ni	1	4
Se	5	1
Mo	5	1
As	4	1
Tl	2	2
Fe	2	2
Mn	3	4
Al	1	3

3.3.3 Organic Contaminants

Along with beneficial organic matter, biosolids also may contain organic chemical contaminants. Though various types of organic contaminants may find their way into the sewer system from consumer or industrial use, many of these organics will be broken down or decomposed during wastewater treatment. Those organics that do not decompose will likely be strongly adsorbed onto the organic matter particles present in biosolids. When biosolids are applied to land, most of these organic chemicals will be decomposed in soil by soil microorganisms. Nevertheless, a

community or sanitary district considering biosolids application to the land should be aware of these potentially harmful organic contaminants cause (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 10).

Sludge can also contain hormones and pharmaceutical substances. Not only urine or faces from human but also from animals secrete these. Antibacterial pharmaceutical substances could possibly constitute a risk of influencing the micro flora of the land (European Commission, p. 88-95).

3.3.4 Salts

Various kinds of salts that can be present in biosolids can be deleterious to seed germination or to growth of young plants if high concentrations of salts accumulate in the rooting zone of soils. Soluble salts are not expected to be a problem with agronomic rates of biosolids, however, particularly in humid regions, where leaching by rainfall will remove excess salts from the root zones. Nevertheless, with high application rates of biosolids (e.g., use for reclamation of disturbed lands) or where industries are contributing high-salt discharges to the sewer system, soluble salt additions by biosolids application should not be overlooked cause (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 10).

3.3.5 Plant Nutrients

Nitrogen (N) may be present in sewage sludge in an inorganic form, such as ammonium (NH_4) or nitrate (NO_3), or in an organic form. The form in which N is present in sewage sludge is a key factor in determining how much N is available to plants, as well as the potential for N contamination of ground water. Generally, inorganic N as NO_3 is the most water-soluble form of N, and therefore is of the most concern for ground-water contamination because of its high mobility in most soil types. Inorganic N in the form of NH_4 can readily volatilize as ammonia (NH_3) when sewage sludge is applied to the soil surface rather than incorporated or injected, and thus may not be available to plants. Organic N must be decomposed by soil

microorganisms, or mineralized to inorganic NH_4 and NO_3, before this form of N is available for plants to use. Therefore, organic N can be considered a slow-release form of N.

The concentrations of organic and inorganic N in sewage sludge are affected by the type of sludge treatment and handling processes used (see Table 3.4). Most of the organic N in sewage sludge is associated with the sludge solids, and thus organic N levels are not appreciably altered by sludge dewatering or drying procedures. In contrast, the water-soluble inorganic forms of N and their concentrations will decrease dramatically during dewatering (e.g., drying beds, centrifuges, presses). Some heat or air drying processes or lime treatment will reduce NH_4 because of NH_3 volatilization, but will not affect NO_3 levels.

Table 3.4 Nutrient levels in sewage sludge from different treatment processes (Sommers, 1977)[a]

Nutrient	Sludge Treatment Process[b]	No. of Samples	Range	Median	Mean
Organic C (%)	Anaerobic	31	18-39	26.8	27.6
	Aerobic	10	27-37	29.5	31.7
	Other	60	6.5-48	32.5	32.6
	All	101	6.5-48	30.4	31.0
Total N (%)	Anaerobic	85	0.5-17.6	4.2	5.0
	Aerobic	38	0.5-7.6	4.8	4.9
	Other	68	<0.1-10.0	1.8	1.9
	All	191	<0.1-17.6	3.3	3.9
NH_4^+-N (mg/kg)	Anaerobic	67	120-67.600	1.600	9.400
	Aerobic	33	30-11.300	400	950
	Other	3	5-12.500	80	4.200
	All	103	5-67.600	920	6.540
NO_3^{--} -N (mg/kg)	Anaerobic	35	2-4.900	79	520
	Aerobic	8	7-830	180	300
	Other	3	—	—	780
	All	45	2-4.900	149	490
Total P (%)	Anaerobic	86	0.5-14.3	3.0	3.3
	Aerobic	38	1.1-5.5	2.7	2.9
	Other	65	<0.1-3.3	1.0	1.3
	All	189	<0.1-14.3	2.3	2.5
K (%)	Anaerobic	86	0.02-2.64	0.30	0.52
	Aerobic	37	0.08-1.10	0.39	0.46
	Other	69	0.02-0.87	0.17	0.20
	All	192	0.02-2.64	0.30	0.40
Na (%)	Anaerobic	73	0.01-2.19	0.73	0.70
	Aerobic	36	0.03-3.07	0.77	1.11
	Other	67	0.01-0.96	0.11	0.13
	All	176	0.01-3.07	0.24	0.57
Ca (%)	Anaerobic	87	1.9-20.0	4.9	5.8
	Aerobic	37	0.6-13.5	3.0	3.3
	Other	69	0.12-25.0	3.4	4.6
	All	193	0.1-25.0	3.9	4.9

[a] Concentrations and percent composition are on a dried solids basis.

[b] "Other" includes lagooned, primary, tertiary, and unspecified sludges. "All" signifies data for all types of sludges.

Aerobic conditions facilitate microbial conversion of other N species to the mobile NO_3 form; conversely, anaerobic conditions inhibit conversion of NH_4 to NO_3 by oxidation. Usually, over 90 percent of the inorganic N in sewage sludge will be in the form of NH_4 unless aerobic conditions have prevailed during sludge treatment. For most liquid sewage sludge collected from an anaerobic digester, essentially all inorganic N will be present as NH_4, constituting from 25 to 50 percent of the total N. The NH_4 concentration in the liquid phase of sludge is relatively constant at a specific treatment plant, although treatment process such as dewatering can substantially lower the NH_4 content to less than 10 percent of the total N. Because the inorganic N content of sewage sludge is significantly influenced by sludge handling procedures, N analysis should be conducted on the actual sewage sludge that is land applied. The amount of inorganic N mineralized in soils is affected by the extent of sludge processing (e.g. digestion, composting) within the sewage treatment plant and will generally be less for well stabilized sludge. The organic N content of sewage sludge can range from 1 to 10 percent on a dry weight basis. Organic N compounds found in sludge are primarily amino acids, indicating the presence of proteinaceous materials (Ryan et al., 1973; Sommers et al., 1972). After application to soils, microbes in the soil will decompose the organic N compounds in sewage sludge, resulting in release of NH_4^+, which can then be assimilated by the crop or vegetation being grown.

It has been indicated that Phosphorus (P) deficiency is the second most important soil fertility problem. Phosphorus in biosolids exists in both organic and inorganic forms. Organic P must undergo mineralization as nitrogen before plants can take it up. However, the use of chemical flocculants in some wastewater treatment processes can decrease P mineralization from sludges while P availability to crops is controlled by soil Fe, Al, and Ca content. On the other hand, many soils contain very high levels of phosphorus (P) due to long term manure application or repeated fertilization with commercial P fertilizer. High concentrations of soil phosphorus may increase P runoff into surface water, which can cause algal blooms that subsequently deplete oxygen for plant and animal life. The potential for such

contamination exists where biosolids are applied on soils whose P concentrations are very high.

All biosolids are typically low in potassium (K) because most of the K remains with the treated effluent that is discharged. Biosolids also contain other essential plant nutrients-calcium, magnesium, sulfur, boron, copper, iron, manganese, molybdenum and zinc. When biosolids are stabilized by high lime treatment, they can also have some value as a liming material for acid soils and can substitute for agricultural lime.

3.3.6 Determining Sewage Sludge Application Rates for Agricultural Sites

Sewage sludge application rates are calculated from data on sludge composition, soil test information, N and P fertilizer needs of the crop grown, and concentrations of trace elements. In essence, this approach views sewage sludge as a substitute for conventional N or P fertilizers in crop production. The number of years that sewage sludge application may be limited based on cumulative pollutant loading rate limits for metals.

The general approach for determining sewage sludge application rates on agricultural cropland can be summarized as follows:

- Nutrient requirements for the crop selected are based on yield level and soil test data. If sewage sludge has been applied in previous years, fertilizer recommendations are corrected for carry-over of nutrients added by previous sludge additions.
- Annual sewage sludge application rates are calculated based on N crop needs, P crop needs, and annual pollutant loading rate limits, where applicable (bagged sludge).
- Supplemental fertilizer is determined from N, P, and K needed by the crop and amounts of N, P, and K provided by sewage sludge application.

- Sewage sludge applications are terminated when the cumulative pollutant loading rate limit is reached if applicable (G. K. Evanylo, 1999b).

The majority of sewage sludge contains roughly equal amounts of total N and P, while crop requirements for N are generally two to five times greater than those for conservative approach for determining annual sewage sludge application rates would involve applying sewage sludge to meet the P rather than N needs of the crop. With this approach, farmers would need to supplement sludge N additions with N fertilizer to achieve the expected crop yield.

3.3.6.1 Agronomic Rate for Nitrogen and Pollutant Limits for Metals

Agronomic rate is defined as the rate that will provide the amount of N needed by the crop or vegetation while minimizing the amount of N that passes through the root zone and enters the ground water. Sewage sludge should have at a rate that is equal to or less than the agronomic rate for N at the application site. Generally, the agronomic rate is the limiting factor regarding application rates for sewage sludge.

3.3.6.2 Calculation of Annual Application Rates

Recommended annual rates of sewage sludge application on cropland are based on the N or P requirements of the crop grown, the N and P levels in the sludge, and the metal concentrations in the sludge for which pollutant limits have been set in the regulations. The fertilizer N recommendation for the crop and yield level expected should be corrected for plant-available N mineralized from prior sludge additions. The basic approach for determining annual application rates of sewage sludge involves using data on sewage sludge composition to calculate maximum potential application rates based on (i) crop N requirements, (ii) crop P requirements, and (iii) pollutant limits in the regulations. In most cases, the actual application rate will be selected from the following two possibilities:

- The annual agronomic rate can be utilized to provide recommended N needs until the limits for metals are reached, unless the sewage sludge meets the pollutant concentration limits, in which case cumulative metal loadings do not need to be tracked. (In some cases, this approach may result in the accumulation of excess P in the soil, which can increase the potential for P entering streams and lakes through surface erosion).
- The annual rate may be limited to a rate where sludge P is equal to fertilizer P recommendations or the P removed by the crop. Nitrogen may be applied at less than the crop N need. This P rate could be followed as long as it did not exceed the agronomic N rate or pollutant loading limits for metals.

Another possibility is that the metals loadings at the site are approaching a CPLR (Cumulative Pollutant Loading Rate) limit, which may result in an application rate that is less than the crop's N or P needs (i.e., sewage sludge that does not meet the pollutant concentration limits for metals). Reaching a CPLR limit terminates CPLR sewage sludge application to land, in which case other options, such as incineration or surface disposal, are likely to be more feasible.

3.3.6.3 Calculation of Supplemental N, P, and K Fertilizer

Once the application rate of sewage sludge has been determined, the amounts of plant-available N, P, and K added by the sludge should be calculated and compared to the fertilizer recommendation for the crop (and yield level) to be grown. If the amount of one or more of these three nutrients provided by the sewage sludge is less than the amount recommended, then supplemental fertilizers will be needed to achieve crop yields.

3.3.7 Selection of Suitable Crops for Fertilization with Biosolids

High N-use crops such as corn, soybean, small grains, and forages will minimize the amount of land needed for biosolids application and will benefit from the N supplying capability of bisolids. Crops grown for their flowering parts, such as

cotton, can produce undesirable amounts of vegetative growth if they continue to accumulate N late in the season. Thus, slow release N sources such as biosolids and manures may impair the quality of such crops; however, biosolids can be used efficiently on other crops in rotation with cotton.

Biosolids can be applied to vegetable crops, but green leafy vegetables tend to accumulate higher concentrations of metals than the grain of agronomic crops. Some scientists have cautioned against using biosolids on vegetable crops because they provide a direct conduit of potentially harmful trace elements from the soil to humans. Therefore, grain and forage crops are better choices for biosolids application than vegetables. Tobacco accumulates heavy metals such as Cd in high concentrations, and the use of biosolids on tobacco land is not recommended (G. K. Evanylo, 1999b).

3.3.8 Public Acceptability

Odor and aesthetics are two concerns quite normally expressed by most citizens if a new biosolids application site is to be located near where they live. Those living downwind of a storage lagoon or spreading areas are most likely to complain of odors, and some people find the appearance of surface applied biosolids visually displeasing. These problems can be managed but must be anticipated and planned for in conducting educational programs.

Citizens are also concerned with the health aspect of land application programs. In addition, some concern has been expressed about the possibility that land applied biosolids might damage crops, livestock or the land itself, resulting in possible financial loss to the farmer or his mortgage lender. Concerns have also been expressed about the possibility of a future loss that might occur if new discoveries were to show an unanticipated hazard from previous biosolids applications. Though there can be no guarantees, experience with agronomic use of biosolids has been very reassuring regarding these concerns, and recent federal and state regulations/rules provide direction to ensure this practice is done safely. Where

biosolids have been applied in accordance with regulations, problems that have occurred are rare and are generally related to inadequate field management or poor biosolids quality (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 11).

The public's concerns can be addressed and alleviated in part by increasing their understanding of how advancements in biosolids technologies and regulations governing the use and disposal of biosolids have resulted in high-quality products that are safe and suitable for use. One very effective approach toward accomplishing public education is to assemble a biosolids "team" that includes representatives from all key community stakeholders including university or other scientists, water quality professionals, public health officials, agricultural groups and farmers, the environmental community, regulatory officials, and the media. Also, the appearance of products is becoming more important; granulized or pellets of dried material may be more acceptable than liquids or slurries.

3.4 Applications Methods

The most appropriate application method for agricultural land depends on the physical characteristics of the sludge and the soil, as well as the types of crops grown. Sludge generally land applied using one of the following methods:

i) sprayed or spread on the soil surface and left on the surface for pastures, range and forest land,

ii) incorporated into the soil after being surface applied or injected directly below the surface for producing row crops or other vegetation. Both liquid and dewatered sludges may be applied to land with or without subsequent soil incorporation.

Liquid sludge can be applied by surface spreading or subsurface injection. Surface methods include spreading by tractor drawn tank wagons, special applicator vehicles equipped with flotation tires, or irrigation systems. Surface application with incorporation is normally limited to soils with less than a 7 percent slope. Sludge is commonly incorporated by plowing or dicing after the liquid has been applied to the

soil surface and allowed to partially dry, unless minimum or no-till systems are being used.

Spray irrigation systems generally should not be used to apply sludge to forage or row crops during the growing season, although a light application to the stubble of a forage crop following a harvest is acceptable. The adherence of sludge to plant vegetation can have a detrimental effect on crop yields by reducing photosynthesis. In addition, spray irrigation increases the potential for odor problems and reduces the aesthetics at the application site.

Liquid sludge can also be injected below the soil surface using tractor-drawn tank wagons with injection shanks and tank trucks fitted with flotation tires and injection shanks. Both types of equipment minimize odor problems and reduce ammonia volatilization by immediate mixing of soil and sludge. Injection can be used either before planting or after harvesting crops, but it is likely to be unacceptable for forages and sod production. Some injection shanks can damage the sod or forage stand and leave deep injection furrows in the field.

Subsurface injection will minimize runoff from all soils and can be used on slopes up to 15 percent. Injection should be made perpendicular to slopes to avoid having liquid sludge run downhill along injection slits and pond at the bottom of the slopes. As with surface application, drier soil will be able to absorb more liquid, thereby minimizing down slope movement.

Dewatered sludge can be applied to cropland by equipment similar to that used for applying limestone, animal manures or commercial fertilizer. Typically, dewatered sludge will be surface-applied and incorporated by plowing or another form of tillage. Incorporation is not used when applying dewatered sludge to forage. Sludge application methods such as incorporation and injection can be used to meet Part 503 vector attraction reduction requirements (G. K. Evanylo, 1999b).

3.5 Scheduling

The timing of biosolids application must be scheduled around tillage, planting and harvesting operations for the crops grown and also can be influenced by crop, climate, and soil properties. Soil moisture is a major consideration affecting the timing of sludge application. Traffic on wet soils during or immediately following heavy rainfalls may result in compaction and may leave deep ruts in the soil, making crop production difficult and reducing crop yields. Muddy soils also make vehicle operation difficult and can create public nuisances by carrying mud out of the field and onto roadways.

3.6 Storage

Storage facilities are required to hold biosolids during periods of inclement weather, equipment break-down, frozen or snow-covered ground, or when land is unavailable due to growth of a crop. Liquid biosolids can be stored in digesters, tanks, lagoons, or dying beds; and dewatered biosolids can be stockpiled. Storage can potentially be provided at either in the treatment plant and land application site(s), or both.

Storage capacity is primarily dependent on the amount of sewage sludge needed at the land application site and the volume of sludge received from the treatment works. Storage capacity should be large enough to handle the volume of sludge generated during the longest projected time interval between applications (Elliott et al., 1990) and may need to be larger depending on climatic factors (see below). For agricultural systems, the time period between applications can range from 3 months to a year, whereas time spans between applications to forest land may be greater than 1 year (Elliott et al., 1990).

Storage capacity influences from the characteristics of sewage sludge and climatic conditions (e.g., liquid sludge might be stored in tanks, while sludge solids may be stockpiled). The designer of land application systems should consider the type of sewage sludge treatment, and retention time which ultimately affects the sludge

characteristic. Additionally, following climatic factors should also be considered in design of a land application system:

- Historical precipitation and temperature records for the application site.
- Regulatory agency requirements pertinent to the land application of sewage sludge on frozen, snow-covered, and/or wet soil.
- Ability of the sewage sludge application equipment being used to operate on wet or frozen soil.
- Drainage characteristics of the application site and associated effects on the time required after precipitation for the soil to dry sufficiently to accommodate equipment.

3.7 Monitoring Program

A final factor to consider is regular monitoring of the biosolids application program. Periodic biosolids analyses are required to determine nutrient and pollutant concentrations so agronomic rates that will provide crop nutrient needs can be calculated. Biannual (every two years) soil fertility testing, including soil pH, will help determine N-P-K fertilizer recommendations and indicate whether any lime must be added to maintain soil pH at 6.0 to 7.0. This type of monitoring is required by Part 503 and/or Part 24. Where high rates of biosolids are used (i.e., a non-agronomic or reclamation rate), additional monitoring of surface and tile drainage waters, groundwater, plant tissue, soil, etc., may be needed and required. However, more intensive monitoring will not be necessary where high quality biosolids are applied at agronomic rates to provide plant nutrients (Lee, W. Jacobs and Deliana, S. McGreary, 2001, p. 30). The minimum frequency of monitoring, record keeping and reporting requirements for all cases is presented in Table 3.5.

Table 3.5 Minimum Frequency of Monitoring, Record Keeping, and Reporting Requirements (Ronald, W. Crites and Sherwood, C. Reed et al., 2001)

Monitoring frequency	
Sludge amounts, dry metric tons per year	**Monitoring frequency**
>0 to <290	Once per year
290 to <1500	Once per quarter
1500 to <15000	Once per 60 days
≥ 15000	Once per month

3.8 Regulatory Framework

Current sludge regulations limit sludge disposal alternatives based on the treatment level provided, pathogen removal, and metals content. At the same time, practical disposal options for sludge involve some form of reuse of the product, whether by direct land application, stabilization, composting, or pelletizing.

All Western European countries and the USA have acts on the use of sludge on farmland, but their legislation differs a great deal. In some countries, the regulations are so strict that only a minor part of the sludge can fulfill the conditions. Although legislations vary a great deal among the countries, the following requirements are common in most of them.

- Pre-treatment (reduction of the water content in sludge, reduction of organic substances, reduction of pathogens)
- Restriction on the amount of heavy metals in sludge
- Restriction on the amount of dry solids and heavy metals spread per unit of land and time
- Restriction on the content of heavy metals in the soil on which sludge is spread, and requirements for the pH of the soil
- Restriction on the amount of nutrients added to the soil (nitrogen and phosphorus)
- Restriction on the choice of crops
- Restricted access conditions to farmland on which sludge is spread
- Legislative compliance control

The following section outlines United States, European, and Turkish regulations relevant to sewage sludge management.

3.8.1 The Regulatory Framework in USA

The use and disposal of sewage sludge and biosolids in the USA is regulated under 40 Code of Federal Regulations (CFR) Part 503, dated 1993. These regulations are risk-based rules for the use of biosolids and include requirements for pollutant metals content, pathogen organism content, and vector attraction reduction.

Subpart D of the Part 503 Regulations describes three classifications of biosolids, and specifies their criteria. Two of the classes (A and B) include indicator bacteria and/or pathogen criteria, and the third type of biosolids is the exceptional quality (EQ) biosolids, which includes both the pathogen and heavy metal criteria. All the information in this section is based on US EPA (1993, 1994) and Tata et al., (1998).

3.8.1.1 Class B Biosolids

Sludge containing $2x10^6$ fecal coliforms, or less, per gram of solids (on dry weight basis) are Class B biosolids. Their viable helminth ova counts are not necessarily reduced to the level of Class A biosolids.

Pathogen requirements for Class B biosolids can be met in three different ways: (i) monitoring of fecal coliforms, (ii) use of a process to significantly reduce pathogens (PSRP) and (iii) use of processed equivalent to PSRP.

In this three alternatives, pathogenic bacteria and enteric viruses are expected to be reduced, as demonstrated by a fecal coliform density in the treated sludge of less than two million most probable number (MPN) or colony-forming units (CFU) per gram total solids sewage sludge (dry weight basis). Since Class B biosolids may stil contain some pathogens, restrictions relating to crop harvesting, animal grazing, and public access apply to their use.

PSRP are processes that have been demonstrated to achieve a 2-log reduction in fecal coliform density. They include aerobic digestion, anaerobic digestion, air drying, composting, and lime stabilization.

3.8.1.2 Class A Biosolids

Biosolids that are sold or given away in a bag or other container for application to land must meet Class A pathogen requirements. Bulk quantities of biosolids applied to other types of land must also meet Class A pathogen requirements in order to be exempt from Class B site restrictions. The objective of Class A requirements is to reduce pathogen densities to below the following detectable limits:

- Fecal Coliform: <1000 MPN/g-dry weight
- Salmonella sp.: <3 MPN/g-dry weight
- Enteric viruses: <1/4 g-dry weght
- Viable helminth ova: <1/4 g-dry weight

There are six alternative requirements for demonstrating Class A pathogen reduction. They are (i) thermally treated sewage sludge, (ii) sewage sludge treated by a high pH/high temperature process, (iv) sewage sludge treaated by unknown processes, (v) the use of further process to further reduce pathogens (PFRP) and (vi) the use of processes equivalent to PFRP.

Processes that have been certified as being equivalent to PFRP by the US EPA and meet the Class A microbiological requirement include (i) a two-stage sludge stabilization process similar to heat treatment, (ii) a modified thermophilic aerobic digestion process, (iii) a modified composting process, (iv) a modified sludge drying process, (v) a modified alkaline stabilization process and (vi) an ozonation process.

In addition, one of the vector (rodents, birds, insects and other organisms that can transport pathogens) attraction reduction requirements must also be met in any one of the six alternatives for the bisolids to be disposed of by land applicatiom or in a

surface disposal site. Vector attraction reduction can be accomplished by stabilizing the sludge to the point at which vectors will no longer be attracted to the sludge, and by restricting access to the sludge (Spinosa; Vesilind, 2001, p. 12-13).

3.8.1.3 Exceptional Quality Biosolids

Exceptional Quality (EQ) biosolids are those that comply with the most stringent heavy metals pollutant concentration limits of the Part 503 regulations and Class A pathogen reduction and vector reduction standards. EQ biosolids are not under the control of the Part 503 regulations and can be land-applied or disturbed, or sold for land application without restriction. The ceiling concentration for the metals is not to be exceeded for either bulk sewage or sewage sludge sold or given away in containers. Limit values for concentrations of heavy metals in sewage sludge intended for agricultural use and in sludge-treated soils are in Annexes I A, I B and I C of the Directive and they summarized in Table 3.6.

Table 3.6 Pollutant concentrations and loading rates of heavy metals (U.S. EPA, 1994)

Pollutant	**CC[(1)] (mg/kg DS)**	**CLR[(2)] (kg/ha)**	**MAVC[(3)] (mg/kg DS)**	**ALR [(4)] (kg/ha/year)**
Arsenic	75	41	41	2.0
Cadmium	85	39	39	1.9
Copper	4300	1500	1500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybden	75	-	-	-
Nickel	420	420	420	21
Selenium	100	100	100	5.0
Zinc	7500	2800	2800	140

[(1)] CC – Ceiling Concentrations

[(2)] CLR - Cumulative Loading Rates

[(3)] MAVC - Monthly Average Concentrations

[(4)] ALR - Annual Loading Rates

There are no scecific treatment methods used by wastewater treatment facilities to remove metals from the resulting sewage sludges. In order to produce biosolids that have metal concentrations below the ceiling limits for land application, wastewater treatment plants have to depend upon effective industrial or trade waste pre-treatment programs. The ultimate metal concentration in the final biosolids is dependent upon the efficiency of metals reduction in the industrial pre-treatment and/or prevention programs (Spinosa; Vesilind, 2001, p. 15).

3.8.2 The Regulatory Framework in European Union

The Directive on waste (75/442/EEC) sets out the principles of the necessary controls where waste materials are to be recycled to the land. More specific controls for land application of wastes have also been compiled from the European Waste Catalogue (classification) and from Directive 86/278/EEC on land spreading of sewage sludge and Directive 91/676/EEC on protection of waters against pollution caused by nitrates from agricultural sources. The Sewage Sludge Directive 86/278/EEC encourages the use of treated sewage sludge in agriculture and regulates its use in such a way as to prevent harmful effects on soil, vegetation, animals and man. To this end, the Directive prohibits the use of untreated sludge on agricultural land unless it is injected or incorporated into the soil. Treated sludge is defined as having undergone "biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use". And, the use of sludge is also prohibited (a) on grassland or forage crops if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed (this period, fixed by the Member States, may not be less than three weeks); (b) on soil in which fruit and vegetable crops are growing, with the exception of fruit trees; and (c) on ground intended for the cultivation of fruit and vegetable crops which are normally in direct contact with the soil and normally eaten raw, for a period of ten months preceding the harvest of the crops and during the harvest itself.

The Directive specifies rules for the sampling and analysis of sludge and soils. It sets out requirements for the keeping of detailed records of the quantities of sludge produced, the quantities used in agriculture, the composition and properties of the sludge, and the type of treatment.

There are limit values for concentrations of heavy metals in soil to which sludge is applied and concentrations of heavy metals in sludge. Limit values for concentrations of heavy metals in soil, in sludge for use in agriculture, and finally limit values for amounts of heavy metals which may be added annually to agricultural land, based on a 10-year average are presented in Annexes 1A, 1B, 1C of the Directive. These limits are shown in Tables 3.7-3.9.

Table 3.7 Limit values for concentrations of heavy metals in the soil (mg/kg DS of a representative sample of soil with a pH of 6 to 7 (86/278/EEC, Annex 1A)

Pollutant	**Limit value[(1)](mg/kg DS)**
Cadmium	1-3
Copper[(2)]	50-140
Nickel[(2)]	10-75
Lead	50-300
Zinc[(2)]	150-300
Mercury	1-1.5
Chromium[(3)]	-

[(1)] Member States may permit the limit values they fix to be exceeded in the case of the use of sludge on land which at the time of notification of this Directive is dedicated to the disposal of sludge but on which commercial food crops are being grown exclusively for animal consumption. Member States must inform the Commission of the number and type of sites concerned. They must also seek to ensure that there is no resulting hazard to human health or the environment.

[(2)] Member States may permit the limit values they fix to be exceeded in respect of these parameters on soil with a pH consistently higher than 7. The maximum authorized concentrations of these heavy metals must in no case exceed those values by more than 50 %. Member States must also seek to ensure that there is no resulting hazard to human health or the environment and in particular to ground water.

[(3)] It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission, within one year following notification of this Directive.

Table 3.8 Limit values for heavy metal concentrations in sludge for agricultural use (86/278/EEC, Annex 1B)

Pollutant	Limit value (mg/kg DS)
Cadmium	20-40
Copper	1000-1750
Nickel	300-400
Lead	750-1200
Zinc	2500-4000
Mercury	16-25
Chromium[1]	-

[1] It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission within one year following notification of this Directive.

Table 3.9 Limit values for heavy metals that may be added annually to agricultural land based on a 10 year average (86/278/EEC, Annex 1C)

Pollutant	Limit value[1] (kg/ha/year)
Cadmium	0.15
Copper	12
Nickel	3
Lead	15
Zinc	30
Mercury	0.1
Chromium[2]	-

[1] Member States may permit these limit values to be exceeded in the case of the use of sludge on land which at the time of notification of this Directive is dedicated to the disposal of sludge but on which commercial food crops are being grown exclusively for animal consumption. Member States must inform the Commission of the number and type of sites concerned. They must also ensure that there is no resulting hazard to human health or the environment.

[2] It is not possible at this stage to fix limit values for chromium. The Council will fix these limit values later on the basis of proposals to be submitted by the Commission within one year following notification of this Directive.

The Directives states that Member States may take more stringent measures than accounted for here if certain conditions exist in that country (86/278/EEC, Article 12). On the other hand, the heterogeneity in ecological and economic conditions makes it very difficult to establish consensus in Europe. In some cases, ecology or the need to preserve the limited agricultural soils in a country is the diving force. Many soils in central Europe are contaminated due to long-term industrial pollution. In other countries, economics is the driving force. Farmers need biosolids as a nutrient source and to reduce their fertilizer costs. It appears that the EU standards set an overall condition fort he countries, yet individual countries, such as Sweden, can have more restrictive standards. Variations among the limit values are presented in Table 3.10 within the EU.

Table 3.10 Limit values of heavy metals in biosolids use for land application between the US and Several European Countries (Epstein E., 2003, p. 188)

Pollutant	**U.S.[(1)]**	**EU**	**NL**	**S**	**DN**	**GR**
Arsenic	41	-	0.15	-	25	-
Cadmium	39	20-40	1.25	2	0.8	5-10
Chromium	1200[(2)]	-	75	100	100	900
Copper	1500	1000-1750	75	600	1000	800
Mercury	17	16-25	0.75	2.5	0.8	8
Lead	300	750-1200	100	100	60-120	900
Nickel	420	300-400	30	50	30	200
Zinc	2800	2500-4000	300	800	4000	2000-250

[(1)] USEPA regulations 40 CFR 503

[(2)] Cr subsequently deleted from regulations

The Commission is working on a new Directive regarding the usage of sludge since 1999. The latest working document is the third draft from the 27 of April 2000 which is a working document elaborated by the Environment Directorate-General in the European Commission. The ambition is to regulate all types of land application

of sewage sludge, septic tank sludge and industrial sludge. Previously, only sludge used as a fertilizer in agriculture has been regulated and the scope is now broadening to include management of sludge on green areas, in silviculture and on reclaimed land (drastically disturbed land that is reclaimed using sludge) (Environment DG, 2000). It is suggested that sludge should be used when there is an agronomic interest for then crops or when the soil might be improved. It is not allowed to use sludge in forest with the exception of plantations, such as short-rotation plantations or plantations for energy crops, and for re-afforestation purposes (Environment DG, 2000).

The limit values of heavy metals in soil are shown in Table 3.11. The limit values are defined for varying pH values. The pH will thereafter decide which limit values for concentrations of heavy metals in the soil that must be followed. If the concentration of an element is higher in a soil than the set threshold values, a competent authority based on a certain evaluation may still allow use of sludge. (Environment DG, 2000).

The limit values for heavy metals in sludge intended for land use and maximum annual quantities of heavy metals that may be added to the soil as a result of sludge use are shown in Tables 3.12 and 3.13 respectively (Environment DG, 2000). As can be seen in the Table 3.12, there are two different limit values for the heavy metal content of the sludge. The sludge producer may choose to follow either the dry matter related or the phosphorus related limit values (Environment DG, 2000).

Table 3.11 Limit values for concentrations of heavy metals in soil (Environment DG, 2000)

Metal	**Limit value (kg/ha and year)**			
	86/278/EEC 6<pH<7	**5<pH<6**	**6<pH<7**	**pH>7**
Cadmium	1-3	0.5	1	1.5
Chromium	--	30	60	100
Copper	50-140	20	50	100
Mercury	1-1.5	0.1	0.5	1
Nickel	30-75	15	50	70
Lead	50-300	70	70	100
Zinc	150-300	60	150	200

Table 3.12 Limit values for concentrations of heavy metals in sludge for use on land (Environment DG, 2000)

Pollutant	**Limit value (mg/kg DS)**		**Limit value (mg/kg P)**
	86/278/EEC	**Proposed**	**Proposed**
Cadmium	20-40	10	250
Chromium	-	1000	25000
Copper	1000-1750	1000	25000
Mercury	16-25	10	250
Nickel	300-400	300	7500
Lead	750-1200	750	18750
Zinc	2500-4000	2500	62500

Regulation of organic compounds and dioxins are considered in this working document. The following substances are considered in the document: halogenated organic compounds *(AOX)*, nonylphenol and nonylphenolethoxylates *(NPE)*, LAS, DEHP, PCB, PAH, and PCDD/PCDF. The limit values for concentrations of these in sludge for land use can be seen in Table 3.14 (Environment DG, 2000).

Table 3.13 Limit values for amounts of heavy metals, which may be added annually to soil, based on a ten years average (Environment DG, 2000)

Pollutant	Limit value (g/ha year)	
	86/278/EEC	Proposed
Cadmium	150	30
Chromium	-	3000
Copper	12000	3000
Mercury	100	30
Nickel	3000	900
Lead	15000	2250
Zinc	30000	7500

Table 3.14 Limit values for the concentration of organic compounds and dioxins in sludge intended for land use (Environment DG, 2000)

Pollutant	Unit	Limit value
Organic Compound		
AOX[(1)]		500
LAS[(2)]		2600
DEHP[(3)]	mg/kg DM	100
NPE[(4)]		50
PAH[(5)]		6
PCB[(6)]		0.8
Dioxins		
PCDD/F[(7)]	ng TE/kg DM	100

[(1)] Sum of halogenated organic compounds.

[(2)] Linear alkylbenzene sulphonates.

[(3)] Di(2-ethylhexyl)phthalate.

[(4)] It comprises the substances nonylphenol and nonylphenolethoxylates with 1 or 2 ethoxy groups.

[(5)] Sum of the following polycyclic aromatic hydrocarbons: acenapthene, phenanthrene, fluorene, flouranthene, pyrene, benzo(b+j+k)fluoranthene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1, 2, 3 - c, d)pyrene.

[(6)] Sum of the polychlorinated byphenils components number 28, 52, 101, 118, 138, 153, 180.

[(7)] Polychlorinated dibenzodioxins/ dibenzofuranes.

In the working document, the usage of sludge on land is restricted. It is not allowed to apply sludge on frozen, water-saturated, flooded, snow-covered land or on soil with a pH less than 5. The quantity of nutrients that is introduced should be adapted to the needs of the crops or the soil according to best practices (Environment DG, 2000).

The working document specifies what kind of treatment of the sludge that is required for different land use. There are two classes: advanced treatment and conventional treatment and the different processes needed are clearly defined. It is further listed how these two classes of sludge may be used on agricultural land, parks and reclamation sites (Environment DG, 2000).

3.8.3 The Regulatory Framework in Turkey

Sludge management becomes one of the most significant environmental problems of Turkey due to increasing number of wastewater treatment plants. Application of treatment plant sludge to land in Turkey is governed by Regulation on Soil Pollution Control (RSPC) issued by the Ministry of Environment and Forestry (RG 25831, 2005). The objective of the RSPC is stated as "to set out the principles of taking required measures in harmony with sustainable development targets for the prevention of soil pollution". RSPC prohibits the sludge from treatment plants from being used in agriculture unless specified requirements are fulfilled. If sludge does not meet these specified thresholds it must be disposed off in some other way; it cannot be land applied.

This regulation is composed of five major sections. Section one provides the objective, scope, legal basis and definitions. Section two lists the obligations regarding the prevention of soil pollution. Section three describes the use of raw (unprocessed) and treated (processed) sludge, and compost on soil. Section four covers the principles and sanctions regarding encouragement, training and inspection. And finally, section five includes the items related to implementation of the regulation.

RSPC comprises the technical, administrative principles and legal permits on application of sludge and compost onto soil, discharge or leakage of waste to the soil, the activities causing the soil pollution. In this regard, limits (maximum permissible concentrations) of various inorganic and organic soil pollutants, maximum allowable metal concentrations of sludge to be disposed off in agricultural lands are presented. Limits on metal concentrations for the soil amendments used in the agriculture are given separately for sludge, soil and together with maximum annual loading rates in Table 3.15 and 3.16. Those limit values are average values calculated for a period of ten years.

Table 3.15 Limit values for concentrations of heavy metals in the soil (RG 25831, 2005)

Pollutants	**Limit value (mg/kg DM) 5<pH<6**	**Limit value (mg/kg DM) (pH>6)**
Lead	50 (2)	300 (2)
Cadmium	1 (2)	3 (2)
Chromium	100 (2)	100 (2)
Copper (1)	50 (2)	140 (2)
Nickel (1)	30 (2)	75 (2)
Zinc (1)	150 (2)	300 (2)
Mercury	1 (2)	1.5 (2)

(1) Ministry of Environment and Foresty (MoEF) may permit the limit values they fix to be exceeded in respect of these parameters on soil with a pH consistently higher than 7. The maximum concentrations of these heavy metals must in no case exceed those values by more than 50 %. The MoEF must also seek to ensure that there is no resulting hazard to human health or the environment and in particular to ground water.

(2) The MoEF may permit the limit values they fix to be exceeded in the case of the use of sludge on land which at the time of notification of this Regulation is dedicated to the disposal of sludge but on which commercial food crops are being grown exclusively for animal consumption.

There are no restriction for any pathogenic features and organic chemical content of sludge in the regulation. And also, technologies for stabilization have not been identified in the Regulation.

Table 3.16 Pollutant concentrations and loading rates of heavy metals in sludge for use on land (RG 25831, 2005)

Pollutant	**Ceiling Concentration (mg/kg DS)**	**Annual Loading Rates (kg/ha and year)**
Lead	1200	1500
Cadmium	40	15
Chromium	1200	1500
Copper	1750	1200
Nickel	400	300
Zinc	4000	3000
Mercury	50	10

CHAPTER FOUR
EXPERIMENTAL STUDIES

4.1 Experimental Procedure

The main objective of this study was to investigate the land use potential of the industrial sludges produced from agro-industry wastewater treatment plants. In this context, characterization study was achived as first. Physical, chemical and biological properties of sludge samples were investigated. Then, the parameters exceeding the limits were determined; and finally treatment studies (i.e. chemical stabilization with lime, thermal treatment and chemical + thermal treatment) were performed to improve the sludge quality for land applications.

Experimental studies were carried out with dewatered sludge obtained from various agro-industry treatment plants. Vegetable processing, meat processsing, fermentation, dairy, distillery, and beverage production were sectors studied in the research. In addition, sludge was also taken from municipal wastewater treatment plant in order to compare the physical, chemical and biological properties of the sludges.

4.1.1 Characterisation of the Agro-Industry Treatment Plant Sludges

During the experimental studies, sludge samples were taken from sludge treatment units of the vegetable processing, meat processsing, fermentation, dairy, distillery, and beverage factories wastewater treatment plants. In the study, vegetable processing sector was represented by three different factory; i.e. vinegar production, pickling, frozen and canned food production). As distilleries, sludge samples were taken from the brewery and arrack (i.e. alcoholic drink made from fermented molasses) production plants. Other sectors (i.e. beverage, meat processing, dairy and fermentation) were also represented with one plant in the study.

Dewatered sludge samples were taken from the outlet of the dewatering units (belt press, fitler press, or drying bed) of the plants and kept at 4 ^{o}C during the experiments. The pH, salinity, solids content, moisture content, organic matter, organic carbon, nitrogen, phosphorus, potassium, iron, magnesium, sodium, calsium as well as heavy metals (Cu, Zn, Cd, Cr, Pb, Ni) were measured to determine the physical and chemical properties of the sludge samples. Besides, fecal and total coliforms were measured within the characterisation study.

4.1.2 Improvement of the SludgeCharacteristics (Treatment Studies)

In the study, treatment studies were performed in order to improve sludge characteristics for land application. During the studies meat processing industry sludges was used due to high concentrations of coliforms in the sludge. Chemical stabilization, thermal stabilization and combination of these methods were performed separately to reduce the coliforms.

4.1.2.1 Chemical Stabilization

According to the current regulations in USA and EU, Class B biosolids may be land applied with certain restrictions. One method for achieving Class B status is to raise the pH of the sludge to above 12 for a minimum 2 hours with an alkaline material. Alternatively, Class B biosolid is any biosolid that meets the criteria of 2 million fecal coliform/g of total solids. Therefore, in the study, chemical stabilization method was used to reduce the coliforms in sludge.

In the study dewatered sludge samples were taken from the outlet of belt press unit of the plant. Stock lime solution (%3 (w/v)) was prepared as first. To achieve sufficient disinfection and meet Class B or conventional standard biosolids referred to EPA and EU regulations, different lime dosages (10-100 ml) were added to sludge. Sludge and lime were mixed manually with a plastic spoon. Then, sludge samples were taken at 2, 6, 24, and 72 hours intervals and pH, solids concentration, and coliform measurements were achieved. For coliform measurements, sludge samples were diluted at 1: 1000000.

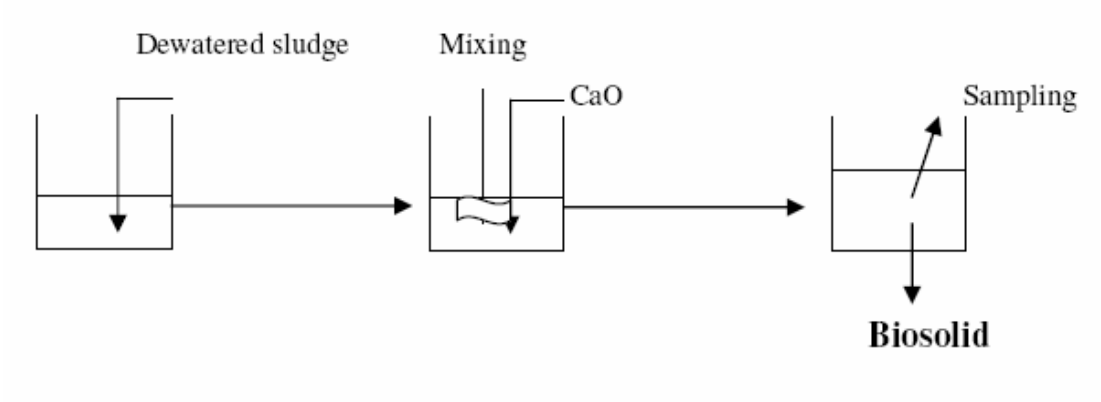

Figure 4.1 Laboratory system used in the chemical stabilization experiments

The membran-filter technique were used to enumerate fecal coliforms in the experiment. A.P. Sincero and G.A. Sincero (2003) resarched that the membrane-filter technique consits of filtering under vacuum a volume of water through a membrane fitler having pore openings of 0.45 μm, placing the filter in a Petri dish and incubating and counting the colonies that developed after incubation. The 0.45-μm opening retains the bacteria on the fitler. The volume of sample to be filtered depends on the bacterial density. Sample volumes that yield plate counts of 20 to 80 colonies on the Petri dish is considered most valid. The standard volume filtered in potable water analysis 100 ml. The M-Endo medium is used for the coliform group and the M-FC medium for the fecal coliforms. The culture medium is prepared by putting an absorbent pad on a petri dish and pipetting anough of the M-Endo medium or M-FC into the pad. After filtration, the mebrane is removed by forceps and placed directly on the pad. The culture is then incubated at 35±0.5 ^{o}C in te case of the coliform group and at 44.5±0.2 ^{o}C in the case of fecal coliforms. At the end of the incubation period of 24±2 hours, the number of colonies that developed are counted and reported as number of organisms per 100 ml. Figure 4.2 shows the graphical presentation of fecal and total coliform testing.

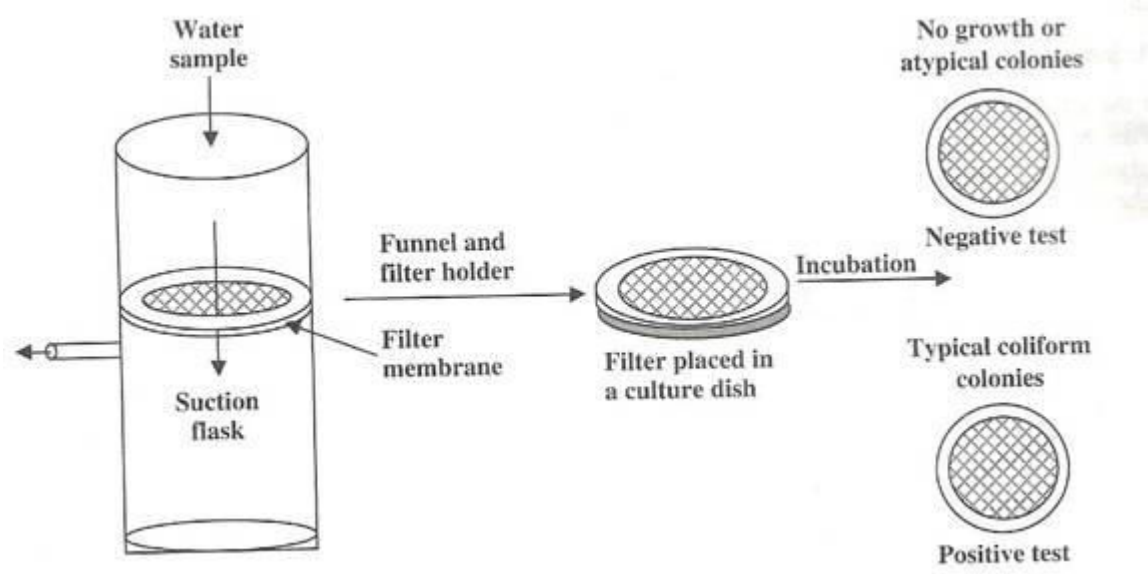

Figure 4.2 Diagram of membrane filter technique for total and fecal coliform testing (From Spellman F.R., Spellman's Standard Handbook for Wastewater Operators, Vol. 1, Technomic Publ., Lancaster, PA, 1999)

Colonies procuced by fecal coliform bacteria on M-FC medium are various shades of blue. Colonies produced by total coliform bacteria on M-Endo medium are various shades of red. Figure 4.3 shows the fecal and total coliform colonies in petri dish.

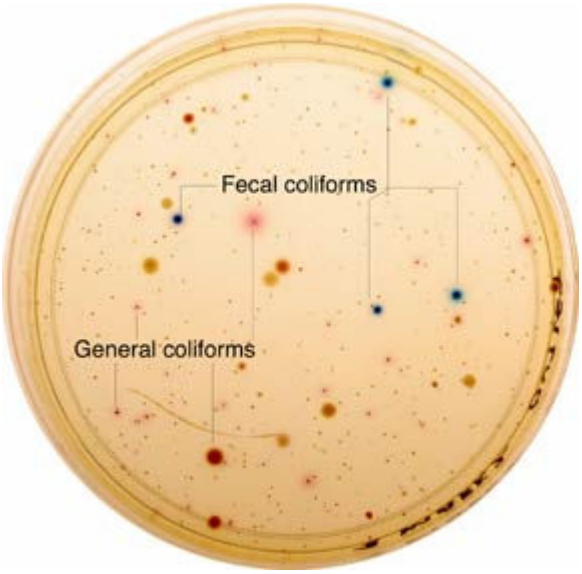

Figure 4.3 Counting fecal (a) and total coliform (b) colonies under magnifying class and expressed as CFU/50 ml

Counted colonies with a low power (10 to 15 magnifications) binocular wide-field dissecting microscope or other optical device. Fecal and total coliform group bacteria density can be calculated using the following equation;

$$Colonies/100ml = \frac{Colonies}{(Dilution)x(Samplevolume)}x100$$

4.1.2.2 Thermal Stabilization

Thermal stabilization was used to attain the US EPA Class A pathogen requirements. According to the US EPA Class A pathogen requirements, the density of fecal coliform in the sludge must be less than 1000 most probable number (MPN) per gram total solids (dry-weight basis). In this framework, sludge samples were heated to the temperature of 50, 70, 180 ^{o}C for the duration of 15, 30, 60, and 120 minutes in order to determine the relationship between heating temperature and fecal coliforms as a common microbial indicators. After heat treatment, sludge samples were diluted at 1: 1000000. The membran-filter technique were also used to enumerate fecal and total coliforms in this experiment. Besides the fecal coliform enumaration, solids concentration, moisture or water content of the heated sludge samples were also measured to determine the effect of thermal operation onto sludge physical characteristics.

4.1.2.3 Chemical + Thermal Stabilization

In the experiments, high pH – high temperature conditions were achieved to reduce fecal coliforms to below detectable levels under US EPA Class A requirements (i.e. < 1000 MPN per gram total solids). The aim of the thermal treatment of the chemically stabilized sludge was to decrease the heating temperature and thus minimize the energy requirement. In this framework, dewatered sludge samples taken from meat processing plant were chemically stabilized by lime. Then, these sludge samples were heated to a temperature of 50, 70, 180 ^{o}C for the duration

of 15, 30, 60, 120 minutes. After thermal treatment, these samples were diluted at 1: 1000000. The membran-filter technique were used to enumerate fecal and total coliforms in the experiment. Besides the fecal coliform enumaration, solids concentration, moisture or water content of the heated sludge samples were also measured to determine the effect of thermal operation onto sludge physical characteristics.

4.2 Analytical Methods

In the study, all parameters were analysed according to Standard Methods (APHA, AWWA, WEF, 1992). The methods used in the measurements are given together with the equipments used in the analysis in Table 4.1.

Table 4.1 Measurement methods and equipments used in the experimental studies

Parameter	**Method**	**Equipment**
pH	Glass electrode	pH meter
Salinity	Electrical conductivity	Conductivity instrument
Total solids cont. (TS, %)	Gravimetric	Furnace (105 ^{o}C)
Moisture content (MC, %)	Gravimetric	Furnace (65 ^{o}C)
Organic matter (OM, %)	Gravimetric	Furnace (550±50 ^{o}C)
Organic carbon (OC, %)	Gravimetric	Furnace (550±50 ^{o}C)
T.C. (MPN/g DS)	Membran filter technique	
F.C. (MPN/g DS)	Membran filter technique	
Total Nitrogen (NO_3-N)	Colorimetric	Spectrophotometer
Phosphate-phosphorus (PO_4-P)	Colorimetric	Spectrophotometer
Potassium (K)	Flame photometric	Atomic absorption spectrometer
Magnesium (Mg)	Flame photometric	Atomic absorption spectrometer
Calcium (Ca)	EDTA titrimetric	
Sodium (Na)	Flame photometric	Atomic absorption spectrometer
Lead (Fe)	Atomic absorption spectrometry	Atomic absorption spectrometer
Heavy metals (Cu, Zn, Cd, Cr, Pb, Ni)	Atomic absorption spectrometry	Atomic absorption spectrometer

4.2.1 Solids content (TS,%) – Moisture content (MC,%)

Solid content and moisture content of the sludges were measured gravimetrically using furnace (Metod 2540D). A reasonable quantity of sludge is placed into a preweighed evaporating dish and weighed the dish plus wet sludge. Following evaporation of the moisture, the dish plus the dry sludge is weighed. The difference equals the moisture driven off, and the solids concentration thus calculated is in terms of *percent solids*, expressed as weight/weight (wt/wt).

4.2.2 pH

pH values of sludge samples were measured according to EPA Method 9045C. 20 grams of sludge sample was mixed with 20 ml of distilled water for 5 minutes and centrifuged at 4000 rpm for 10 minutes. The pH value of the supernatant was measured by HANNAH HI 8314 pH meter.

4.2.3 Salinity

Salinity was originally conceived as a measure of the mass of dissolved salts in a given mass of solution. Because of its high sensitivity and ease of measurement, the conductivity method is the most commonly used to determine salinity. In the experiments, salinity measurents were done according to Standard Methods (Method 2520C).

4.2.4 Organic matter (OM,%)

It is essential to consider the organic fraction of sludge that is to be reused for agricultural proposes. The relatively high level of organic matter in sludge allows the sludge to be used as a soil conditioner to improve the physical properties of soil (e.g., increased water infiltration and water-holding capacity). The organic content of the sludge samples was evaluated by measuring the volatile suspended solids (VSS) concentration. The VSS concentration was measured by baking the total solids

samples at 550°C for one hour according to Standard Method procedure 2540D (APHA, AWWA, WEF, 1992).

4.2.5 Organic carbon (OC,%)

Organic carbon was measured according to Standard Method Procedure 2540E. Dried samples were combusted at 550°C for 4 hours and differences between the initial and final weights were used to determine the organic carbon content. In the experiments, MEMMERT LM 100-800 furnace was used for combustion.

4.2.6 Total Nitrogen

Nitrogen content was measured as Total Kjeldahl Nitrogen by wet digestion (Method 4500-NH_3B).

4.2.7 Fecal Coliform (F.C.)

Fecal coliform bacterial densities were determined by the membrane fitler (MF) technique according to Standard Method Procedure 9222D. The MF procedure uses an enriched lactose medium and incubation temperature of 44.5±0.2 ^{o}C within 24 hours.

4.2.8 Total Coliform (T.C.)

Total coliform bacterial densities were determined by the membrane fitler (MF) technique according to Standard Method Procedure 9222B. The MF procedure uses an enriched lactose medium and incubation temperature of 35±0.5 ^{o}C within 24 hours.

4.2.9 Primary (P, K), and Secondary Plant Nutrients (Fe, Mg, Na, Ca), and Heavy Metals (Cu, Zn, Cd, Cr, Pb, Ni)

Total phosphorus content was measured according to Standard Method 4500-P D. Following to acid extraction of the samples, phosphorus contents of standard and sample solutions were determined by using spectrophotometer. K, Fe, and Mg were analyzed by ICP (Method 3030D). EDTA titrimetric method (Method 3500-Ca B) was used to measure Ca content. Sodium content was measured by photometric method (Method 3500 Na B). Acid axtraction procedure (EPA Method 3050B) was also used in the heavy metal analysis. Cu, Zn, Cd, Cr, Pb, Ni concentrations were measured using Ati Unicam 929/1011 AA Spectrometer.

CHAPTER FIVE
RESULTS & DISCUSSIONS

5.1 Characteristics of the Agro-Industry Treatment Plant Sludges

Although agricultural recycling of sewage sludge has become a common practice over the past several decades, the application of sludge generated by industrial wastewater treatment plants is limited. This may be due to fears of the accumulation of toxic matter in soils and plants. However, the accumulation of heavy metals and their availability to plants depend strongly on the composition of the sludge, the application rate, soil properties, and the crop species. Therefore, certain industries such as food (vegetable) processing, the tobacco industry, pulp and paper production, fermentation industries, beverage, distilleries, and dairy industry have considerable potential due to the low heavy metal content and high organic matter content of their sludges.

In this research, meat processing, vegetable processing, fermentation, dairy, distillery, and beverage (non-alcoholic) production industries were studied in order to examine the land use potential of the industrial sludges. In this framework, characterization study was achieved as first. Physical, chemical and biological properties of sludge samples were investigated. The results of the characterization studies are presented in the following sections.

5.1.1 The Meat Processing Industry Treatment Plant Sludge

5.1.1.1 Process Description

The meat processing includes the slaughtering of animals (cattle), processing of the carcasses into cured, canned, and other meat products, and the rendering of inedible (hair, bones, feathers) and discarded residues into useful by-products. In rendering unit, powdered form blood is produced and then used in food for the animals; and fat wastes are also used in soap industry. The wastewater is mainly

generated from washing of the carcasses and thus contains blood, manure, hair, fat, feathers and bones. The wastewater is characterized by high organic matter content due to contamination with blood; and contains oil and grease, nutrients, and chlorine as well as disease-causing organisms.

The meat processing treatment plant facility is capable of treating a flow of 1750 m^3/day. The treatment plant is composed of screening, equalization, neutralization, chemical treatment (coagulation and flocculation), primary sedimentation, and biologic treatment (extended aerated activated sludge) facilities. The sludge is generated from chemical and biological treatment stages and withdrawn by pumps to the thickener. Afterward, sludge is dewatered by using belt press in the examined plant.

Experimental studies were performed with dewatered sludge obtained from belt press unit. The physical, chemical and biological features of the sludge samples were investigated to determine the sludge characteristics. The results of the characterization study are presented in Tables 5.1-5.3. The physico-chemical parameters of the meat processing industry sludge are given in the Table 5.1. The pH value of the sludge was around 7.2. In literature, pH value of the sewage sludge is stated as generally in range of 7 to 8 unless lime is added during the wastewater treatment process (Epstein, 2003). Here, the pH of the meat processing sludge has shown neutral characteristics and thus make available it for land uses. Salinity of the sludge was measured as 50.5 ppm (average). Since curing is applied for meat preservation, chlorine levels may be very high (up to 77000 mg/l). Dry matter content of the sludge samples was around 20-25%. In literature, typical dry matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. However, presently, sludge generated in the plant has been deposited in the landfill site. Dry matter content is one of the principal criteria for the reception of the sludge to the landfill site. The sludge has to have dry matter content greater than 35% (SWCR, 1991). Therefore,

performance of the dewatering units may be improved considering the landfill reception standards.

The organic content of biosolid varies, depending on the quality of the wastewater and extent of treatment. For the meat processing industry, organic matter content of the sludge was measured as 78% that can be considered as quite high. In addition, the organic carbon content of the sludge was determined as 36% (as an average). In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

The results of an extensive survey on plant nutrients in sewage sludge are reported by Vesilind and Spinosa (2001). According to their study, the fertilizing value of 6000 analyzed sewage sludge samples is varied between 0.1-246 g/kg DS. The average N content is 38.4 g/kg DS in the same literature. Similarly, total nitrogen of sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). Those references are compared with the measured N concentrations in this study. As a result, the sludge was deficient in terms of N and thus fertilizing capability is limited for agricultural uses. On the other hand, phosphorus content was relatively higher than nitrogen content (i.e. ~ 20 mgP/kg). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

All biosolids are typically low in potassium (K) because most of the K remains with the treated effluent that is discharged. Potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). Potassium content was measured as 724.7 mg/kg, and thus it was also deficient nutrient for meat processing sludge.

Table 5.1 Physico-chemical properties of the meat processing industry sludge

Parameters	Unit	Meat Industry Sludge Samples	
		I	II
pH		7.20	7.27
Salinity	ppm	63.84	37.19
Dry Solids	%	19.75	25.07
Moisture Content	%	80.25	74.93
Organic Matter	%	76.88	80.72
Organic Carbon	%	40.00	32.51
Total Nitrogen	mg/kg	9.7	8.3
Phosphorus	mg/kg	14.5	26.19
Potassium	mg/kg	1137	312.4
Iron	mg/kg	18850	5696
Magnesium	mg/kg	1484	4086
Calcium	mg/kg	19390	9476
Sodium	mg/kg	665.4	1396

In general, meat processing industry sludge was deficient in terms of secondary plant nutrients. Calcium content of the sludge was measured as 14.4 g/kg DS (average). In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. When literature values compared with the results one may conclude that relatively lower calcium content was measured in the meat processing industry sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the meat processing industry sludge was in ranged between 1484 and 4086 mg/kg DS, thus magnesium content in sludge was insufficient for agricultural uses. Nutrient deficiency was also observed in terms of sodium. Measured sodium concentration was 1030 mg/kg while 5700 mg Na/kg is attained in sewage sludge (Sommers, 1977). Among the secondary plant nutrient,

particularly iron was sufficient for agricultural uses. Because, measured iron content of the meat processing industry sludge was 12273 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Heavy metal concentrations of the meat processing industry sludge are presented in Table 5.2 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.2, heavy metals concentrations in the sludge are much lower than the tolerance levels.

Table 5.2 Heavy metal concentrations of the meat processing industry sludge

Samples	**Heavy Metals (mg/kg)**					
	Cu	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
Sample I	64.69	1581	0.778	33.72	18.78	27.76
Sample II	28.93	492.1	0.605	9.212	4.652	12.85
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control regulations (SPCR)

As it can be stated in previous sections, fecal coliform, an indicator organism when present in large numbers, indicates the potential presence of pathogens. In the experiments, sludge samples were analyzed to determine the concentrations of fecal and total coliform bacteria. The densities of the fecal and total coliforms of the dewatered sludge samples are given in the Table 5.3.

Table 5.3 Fecal and total coliform densities of the meat processing industry sludge

Sludge	**Fecal coliform (MPN/g DS)**	**Total coliform MPN/g DS)**
Sample I	$1.66*10^6$	$3.32*10^6$
Sample II	$1.82*10^6$	$3.64*10^6$

Average fecal and total coliform densities were 1.74 million MPN/g DS and 3.5 million MPN/g DS, respectively. Since both sewage sludge and animal (meat) processing waste are largely derived from mammalian faecal material, the magnitudes of the coliforms in the examined industry sludge was not changed

significantly. Regarding to the coliform parameter, the meat processing sludge is characterized as Class B and it should be stabilized before land use.

5.1.2 Distillery Industry Treatment Plant Sludge

5.1.2.1 Process Description

As distilleries, sludge samples were taken from the brewery and raki (arrack) production plants. The raki production process includes cleaning of the dried grapes, fermentation and the alcohol production. The alcoholic liquid is then distilled in distillation columns and turns into suma (i.e. suma production). In raki production, suma is taken into a tank for maturation, softening and aging for a period of 1–4 months where anise seeds are added for aromatic taste. Wastewater generated from raki production has low pH, high organic matter, nutrients (i.e. nitrogen and phosphorus), and high concentrations of dissolved solids.

Treatment plant is capable of treating a flow of 320 m^3/day. The treatment plant is composed of screening, grit removal, equalization, neutralization, chemical treatment (coagulation and flocculation), primary sedimentation, and biologic treatment facilities. The sludge is generated from both chemical and biological treatment stages and withdrawn by pumps to the gravity thickener. After thickening, anaerobic digestion is used for stabilization and then dewatered in press filter. Experimental studies were performed with dewatered sludge obtained from filter press unit. The physico-chemical and biological properties of the sludge were presented in Tables 5.4-5.6.

Another sludge sample was taken from a brewery industry treatment plant. Brewing beer begins with the harvesting and cleaning of barley or other cereal grains. When steeped in water, the grain begins to germinate. Once a certain ratio of starch, protein and enzymes is reached, germination is arrested through heating. The grain is now considered malt. Malt is milled and combined with hot water to make mash, which is then left alone while the extracted enzymes convert malt's insoluble

starches into fermentable sugars. When this process is complete, the malt extract, and the solids, or spent grains, are filtered out. To flavor the beer, hops are added to the sweet wort, which is boiled to release the hops' oils. The wort is again filtered, leaving behind spent hops, or trub. Yeast is then added to cooled wort to ferment its sugars into alcohol. Carbon dioxide is produced during fermentation. When fermentation is complete, the wort is now beer, and the yeast is removed by filtration, settling or centrifugation. Some yeast is set aside for the next batch of wort. The beer is then further conditioned depending on the desired character (lager, ale, etc.). A final filtration removes any remaining sediment, and the beer is either sealed in bottles or cans and then pasteurized, or pasteurized and placed in sterilized kegs and tanks. Wastewater sources are bottle wash water, which contains almost no organic components; waste beer; and the water used during filtering, screening and pressing activities prior to fermentation. The brewery wastewater has very high BOD value, high nitrogen content, and low total dissolved solids.

Treatment facility is consisted of screens, equalization tank, rapid and slow mixing tanks, neutralization tank, primary sedimentation tank, aeration tank, final sedimentation tank, and sludge dewatering units. Experimental studies were performed with dewatered sludge.

The physical, chemical and biological features of the sludge samples were investigated to determine the sludge characteristics. The results of the characterization study are presented in Tables 5.4-5.6. The physico-chemical parameters of the meat processing industry sludge are given in the Table 5.4. The pH values of the sludges produced in distilleries were at neutral range. In literature, pH value of the sewage sludge is stated as generally in range of 7 to 8 (Epstein, 2003). In this study, neutral characteristics of the sludge make available it for land uses. Salinity measurements show that sludge samples has highly saline thus can be result in increase in salt concentrations in soil. Dry matter content of the sludge samples were 18.8% in the raki manufacturing and 19.2% in the brewery plant. In literature, typical dry matter contents of various biosolid’s processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid

content of the sludge has shown that the sludge can be applied to the land. However, presently, sludge generated in the plant has been deposited in the landfill site. Dry matter content is one of the principal criteria for the reception of the sludge to the landfill site. The sludge has to have dry matter content greater than 35% (SWCR, 1991). Therefore, performance of the dewatering units may be improved considering the landfill reception standards. The organic matter contents of the sludge samples were about 42-43%. Organic matter contents of these two distillery plants (i.e. raki and brewery) were 71.6% and 78.9%, respectively. In addition, the organic carbon content of the sludges were determined as 42.6 and 43.3% for raki and brewery industries. In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

The results of an extensive survey on plant nutrients in sewage sludge are reported by Vesilind and Spinosa (2001). According to their study, the fertilizing value of 6000 analyzed sewage sludge samples is varied between 0.1-246 g/kg DS. The average N content is 38.4 g/kg DS in the same literature. Similarly, total nitrogen of sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). Those references are compared with the measured N concentrations in this study. As a result, the sludge was deficient in terms of N and thus fertilizing capability is limited for agricultural uses. On the other hand, phosphorus content was relatively higher than nitrogen content (i.e. 9.45 mgP/kg for raki industry and 15.20 mgP/kg for brewery industry). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

Table 5.4 Results of the physico-chemical properties of the distillery industry sludge

Parameters	Unit	Distillery Industry Sludge Samples		
		D-I (Raki)	D-II (Brewery)	
		S I	S II	S III
pH		7.84	7.05	8.11
Salinity	ppm	42.73	68.06	35.08
Dry Solids	%	18.80	22.85	15.48
Moisture Content	%	81.20	77.15	84.52
Organic Matter	%	71.57	92.17	65.63
Organic Carbon	%	42.56	46.84	39.78
Total Nitrogen	mg/kg	8.7	7.9	7.3
Phosphorus	mg/kg	9.45	1.89	28.52
Potassium	mg/kg	1078	944.6	2360
Iron	mg/kg	572.8	1214	660.4
Magnesium	mg/kg	2858	707.0	4244
Calcium	mg/kg	3981	6314	10010
Sodium	mg/kg	2032	2227	1989

Potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). Potassium content was measured as 1078 and 1652 mg/kg for raki and brewery industries respectively, and thus it was also deficient nutrient for meat processing sludge. In general, distillery industry sludges were deficient in terms of secondary plant nutrients. Calcium content of the sludges were measured as 3981 mg/kg DS in raki production and 8162 mg/kg DS in brewery production. In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. When literature values compared with the results one may conclude that relatively lower calcium content was measured in the distillery industry sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the sludges obtained from raki and brewery manufacturing were 2858 mg/kg and 2475 mg/kg. Thus, magnesium contents of these two industry sludges were insufficient for agricultural uses. Nutrient deficiency was also observed

in terms of sodium. Measured sodium concentration was around 2000 mg/kg for each plant while 5700 mg Na/kg is attained in sewage sludge (Sommers, 1977). Finally, iron contents of the sludges were also insufficient for agricultural uses. Because, measured iron content of the raki and brewery sludge was 572.8 and 937.2 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Table 5.5 Heavy metal concentrations of the distillery treatment plant sludge

Sludge Samples	**Heavy Metals – (mg/kg)**					
	Cu	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
D-I	35.54	334.5	2.397	5.628	3.913	18.45
D-II	15.06	158.4	0.509	11.93	21.86	6.877
D-II	9.982	155.9	0.605	9.212	4.136	6.724
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

Heavy metal concentrations of the meat processing industry sludge are presented in Table 5.5 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.5, heavy metals concentrations in the sludge are much lower than the tolerance levels.

In the experiments, sludge samples were analyzed to determine the concentrations of fecal and total coliform bacteria. The densities of the fecal and total coliforms of the dewatered sludge samples are given in the Table 5.6. In D-I (i.e. raki production), average fecal and total coliform densities were 1.76 million MPN/g DS and 3.5 million MPN/g DS, respectively. In D-II (i.e. brewery production) average fecal and total coliform densities were 1.4 million MPN/g DS and 2.8 million MPN/g DS, respectively. Regarding to the coliform parameter, sludges from the distilleries are categorized as Class B and it should be stabilized before land use.

Table 5.6 Fecal and total coliform densities of the distillery industry sludge

Sludge Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
D-I	$1.76*10^6$	$3.52*10^6$
D-II	$1.5*10^6$	$3.00*10^6$
D-II	$1.3*10^6$	$2.6*10^6$

5.1.3 Dairy Industry Treatment Plant Sludge

5.1.3.1 Process Description

Dairy wastewater mainly results from storage tank washing, pipeline washing and pasteurization processes which constitute almost two-thirds of the effluents. It contains milk solids, detergents, sanitizer, and milk wastes. Treatment facility is consisted of equalization tank, primary sedimentation tank, flotation (DAF), neutralization, biologic treatment (anaerobic treatment), sedimentation tank, chemical treatment, and sludge dewatering units. Sludge from DAF is pumped to the thickener, and then dewatered by using a decanter. The physico-chemical and biological properties of dairy (i.e. milk production) industry sludge are presented in Tables 5.7-5.9.

Among the industries examined in this study, the highest pH value was measured in the dairy industry sludge (i.e. 11.90). Alkaline pH conditions may favor land application due to lower solubility of metal ions in soil which reduces the metal uptake by plants. Salinity of the sludge was measured as 65.95 ppm (average). Dry matter content of the sludge samples was approximately 22%. In literature, typical dry matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. The organic content of biosolid varies, depending on the quality of the wastewater and extent of treatment. For the dairy industry, organic matter content of the sludge was measured as 67.7% that can be considered as quite high. In addition, the organic carbon content

of the sludge was determined as 46% (as an average). In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

Table 5.7 Physico-chemical properties of the dairy industry sludge

Parameters	Unit	Sludge Sample
pH		11.90
Salinity	ppm	65.95
Dry Solids	%	21.95
Moisture Content	%	83.92
Organic Matter	%	67.68
Organic Carbon	%	46.07
Total Nitrogen	mg/kg	11.1
Phosphorus	mg/kg	18.1
Potassium	mg/kg	1056
Iron	mg/kg	2214
Magnesium	mg/kg	856.4
Calcium	mg/kg	14250
Sodium	mg/kg	948.2

The results of an extensive survey on plant nutrients in sewage sludge are reported by Vesilind and Spinosa (2001). According to their study, the fertilizing value of 6000 analyzed sewage sludge samples is varied between 0.1-246 g/kg DS. The average N content is 38.4 g/kg DS in the same literature. Similarly, total nitrogen of sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). Those references are compared with the measured N concentrations in this study. The total nitrogen content of the dairy plant sludge was

11.1 mg/kg. As result, the sludge was deficient in terms of N and thus fertilizing capability is limited for agricultural uses. On the other hand, phosphorus content was relatively higher than nitrogen content (i.e. ~ 18 mgP/kg). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Thus, similarly to nitrogen parameter, sludge is poor in terms of phosphorus. Potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). In the dairy industry sludge, potassium content was measured as 1056 mg/kg, and thus it was also deficient nutrient for meat processing sludge.

In general, dairy industry sludge was deficient in terms of secondary plant nutrients. Calcium content of the sludge was measured as 14.2 g/kg DS (average). In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. When literature values compared with the results one may conclude that relatively lower calcium content was measured in the meat processing industry sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the examined industry sludge was 856.4 mg/kg DS, thus magnesium content in sludge was insufficient for agricultural uses. Nutrient deficiency was also observed in terms of sodium. Measured sodium concentration was 948.2 mg/kg while 5700 mg Na/kg is desired in sewage sludge (Sommer, 1977). Finally, iron was also insufficient for agricultural uses. Because, measured iron content of the dairy industry sludge was 2214 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Heavy metal concentrations of the dairy industry sludge are presented in Table 5.8 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.8, heavy metals concentrations in the sludge are much lower than the tolerance levels.

Table 5.8 Heavy metal concentrations of the dairy industry sludge

Sludge Sample	Heavy Metals – (mg/kg)					
	Cu	Zn	Cd	Cr	Pb	Ni
Sample I	19.11	212.2	0.324	18.06	7.19	22.12
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

In the experiments, sludge samples were analyzed to determine the concentrations of fecal and total coliform bacteria. The densities of the fecal and total coliforms of the dewatered sludge samples are given in the Table 5.9. Average fecal and total coliform densities were 2.4 million MPN/g DS and 4.8 million MPN/g DS, respectively. Regarding to the coliform parameter, sludges from the dairy industry are categorized as Class B and it should be stabilized before land use.

Table 5.9 Fecal and total coliform densities of the dairy industry sludge

Sludge Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
Sample I	$2.4*10^6$	$4.8*10^6$

5.1.4 Vegetable Processing Industry Treatment Plant Sludge

5.1.4.1 Process Description

In the study, three different vegetable processing industry treatment plants were investigated. The first examined industry is denoted as VP-I in the thesis. The wastewater is derived from fermentation processes (vinegar production, cucumber pickling), processing of fresh vegetables (slicing and packing of iceberg lettuce and spinach), and domestic sources (cafeteria, toilets, showers). The wastewater from the pickling process is usually characterized by high chloride content, organic matter content, low pH, and high suspended solids. In contrast, the vinegar process and the iceberg lettuce and spinach washing processes are typified by high organic matter content and relatively low chloride concentrations (Dolgen and Alpaslan, 2000). The

treatment facility is capable of treating a flow of 90m^3/d and includes primary, secondary, and sludge treatment stages. Primary treatment consists of screen, equalization and neutralization units. Secondary treatment includes a biological process known as extended-aeration activated sludge, which utilizes aerobic microorganisms to help degrade the organic matter. Sludge that settles out in the aeration tanks is pumped into a thickener that increases the dry matter content. After the thickening process, sludge is dewatered using drying beds. The sludge's dry matter content is raised from 3% to between 25% and 30% in the drying beds before disposal in a landfill.

In the second plant (i.e. VP-2), vegetables and fruits are processed to increase the shelf life of fruits and vegetables. Processing steps include cleaning, slicing, peeling, and freezing. Plant operation is often seasonal and thus wastewater characteristics varies depending on the vegetables or fruits processed in the plant. The wastewater coming from vegetable processing is characterized by its high organic content, solid matter, nutrients (mainly phosphorus). The wastewater treatment plant includes screens, aerated grit chambers, equalization tank, chemical treatment (coagulation and flocculation), biologic treatment (aeration tank and final sedimentation tank), and sludge treatment units. The sludge is generated only from the biologic unit and withdrawn by pumps to the thickener. After the thickening process, drying beds are used for sludge dewatering purposes. Dry matter content of the sludge after the thickener is about 1.5% and increased to 25-35% in the drying beds.

Finally, in the last vegetable-processing treatment plant (VP-3), canned vegetables are produced. The wastewater is mainly generated from the pepper, tomatoes, and mushroom slicing, canning, and desalting units. The capacity of the treatment plant is 100 m^3/day. The treatment plant is composed of screening, equalization, neutralization, biologic treatment (sequentially operated biologic treatment processes) and sludge treatment facilities. Sludge taken from the bottom of the settling tanks (biologic treatment unit) is mixed in the sludge holding tanks and pumped to the sludge dewatering unit. Mechanical dewatering tables and belt presses

are used to decrease the water content of sludge. Dewatered sludge is stabilized by lime addition and a product that is harmless to the nature and environment obtained.

Experimental studies were performed with dewatered sludge obtained from belt press unit. The physical, chemical and biological features of the sludge samples were investigated to determine the sludge characteristics. The results of the characterization study are presented in Tables 5.10-5.12. The physico-chemical parameters of the meat processing industry sludge are given in the Table 5.10. The pH value was varied between 7 and 8, which was harmonious with the literature. The lowest salinity was measured in VP-1 (25.9 ppm) while elevated concentrations were measured in both VP-2 and VP-3. Dry solid content of the sludges after dewatering process were changed from 21.2 to 25.6. The highest dry solid was determined in VP-3. In literature, typical dry matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. However, presently, sludge generated in the plant has been deposited in the landfill site. Dry matter content is one of the principal criteria for the reception of the sludge to the landfill site. The sludge has to have dry matter content greater than 35% (SWCR, 1991). Therefore, performance of the dewatering units may be improved considering the landfill reception standards. The Organic matter content of the sludges were quite high for each industry. The highest OM content was obtained in VP-2 (i.e. 76.9%), and followed by VP-1 and VP-3, respectively. In addition, the organic carbon content of the sludges was determined as 45.4, 46.1 and 32.9% for VP-1, VP-2, and VP-3 respectively. In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommer, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

The results of an extensive survey on plant nutrients in sewage sludge are reported by Vesilind and Spinosa (2001). According to their study, the fertilizing value of 6000 analyzed sewage sludge samples is varied between 0.1-246 g/kg DS. The average N content is 38.4 g/kg DS in the same literature. Similarly, total nitrogen of

sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). Those references are compared with the measured N concentrations in this study. Total nitrogen was ranged between 8-10 mg/kg which was quite insufficient for agricultural applications. On the other hand, phosphorus content was relatively higher than nitrogen content (i.e. 23.7 mgP/kg in VP-1, 42.6 mgP/kg in VP-2, and 16.72 mgP/kg in VP-3). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

Table 5.10 Physico-chemical properties of the vegetable processing industry sludge

Parameters	**Unit**	**Sludge Samples**				
		VP 1		**VP-2**		**VP-3**
		I	**II**	**I**	**II**	
pH		8.45	7.89	8.07	8.42	7.75
Salinity	ppm	20.22	31.65	53.81	57.51	43.79
Dry Solids	%	22.12	20.32	23.73	19.72	25.60
Moisture Content	%	77.88	79.68	76.27	80.28	74.40
Organic Matter	%	74.14	68.51	87.88	65.93	68.94
OrganicCarbon	%	45.27	45.68	45.07	47.76	32.97
Total Nitrogen	mg/kg	14.7	7.2	8.8	8.7	8.2
Phosphorus	mg/kg	26.29	21.20	14.77	70.38	16.72
Potassium	mg/kg	1038	1568	2221	1842	308.2
Iron	mg/kg	1979	1665	3208	2274	1183
Magnesium	mg/kg	9866	9330	2003	13080	13410
Calcium	mg/kg	20870	17150	5282	1842	23000
Sodium	mg/kg	1352	1729	1020	123.1	163.1

Regarding to secondary plant nutrients, the lowest potassium content was obtained in VP-3 (308 mg/kg) and followed by VP-1 (1303 mg/kg) and VP-2 (2032 mg/kg). Potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). And thus potassium was also deficient nutrient for vegetable processing sludge. In general, vegetable industry sludges were deficient in terms of secondary plant nutrients. Iron content was ranged from 1138 to 2741 mg/kg. VP-2 has highest iron content (2741 mg/kg). Since measured iron contents of the sludge samples were lower than the literature value (i.e. 13000 mg/kg) land application of the sludges for agricultural purposes is limited. On the other hand, calcium and magnesium contents of the sludge were quite high. The highest concentrations of calcium and magnesium were measured in VP-3 (23000 mgCa/kg and 13410 mgMg/kg). In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. Thus, both calcium and magnesium contents of the vegetable industry sludges were insufficient for agricultural uses. The highest Na content was obtained as 1540 mg/kg for VP-1. Since 5700 mg Na/kg is attained in sewage sludge (Sommers, 1977) nutrient deficiency was also observed in terms of sodium.

Heavy metal concentrations of the vegetable processing industry sludge are presented in Table 5.11 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.11, heavy metals concentrations in the sludge are much lower than the tolerance levels.

In the experiments, sludge samples were analyzed to determine the concentrations of fecal and total coliform bacteria. The densities of the fecal and total coliforms of the dewatered sludge samples are given in the Table 5.12. Average fecal coliform densities were determined as 1.6, 1.37, and 1.2 million MPN/g DS for VP-1, VP-2, and VP-3 respectively. Regarding to the coliform parameter, sludges from the vegetable industry are categorized as Class B and it should be stabilized before land use.

Table 5.11 Heavy metal concentrations of the vegetable processing sludge

Sludge	Heavy Metals – (mg/kg)					
	Cu	Zn	Cd	Cr	Pb	Ni
VP-1						
Sample I	36.41	231.0	0.858	56.44	11.94	27.20
Sample II	22.61	276.4	1.789	44.47	39.97	19.79
VP-2						
Sample I	32.71	197.0	0.515	232.5	2876	15.53
Sample II	27.37	202.6	0.678	14.86	3.5	18.28
VP-3	21.25	102.3	0.576	9.175	1.381	24.38
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

Table 5.12 Fecal and total coliform densities of the vegetable processing industry sludge

Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
VP-1		
Sample I	$1{,}8*10^6$	$3.6*10^6$
Sample II	$1.4*10^6$	$2.8*10^6$
VP-2		
Sample I	$1.3*10^6$	$2.6*10^6$
Sample II	$1.44*10^6$	$2.88*10^6$
VP-3	$1.2*10^6$	$2.4*10^6$

5.1.5 Fermentation Industry Treatment Plant Sludge

5.1.5.1 Process Description

Molasses is used for the yeast production by fermentation processes. Following to the yeast milk production, cooling, separation, filtration processes are applied and then wet and dry yeast is produced. The wastewater consists of cooling water, washing water, domestic water and drainage water. Treatment plant includes

equalization, anaerobic treatment (acid and methane reactors and settling tanks), aerobic treatment, and lagoons. Process wastewater (900-1200 m^3/day) is treated anaerobically as first; then mixed with the domestic wastewater and cooling water; and the mixture is treated in the aerobic treatment units. Aerobic treatment is followed by logoons for pH adjustment. Sludge is obtained from both anaerobic and aerobic treatment units; following to the dewatering in belt filter disposed in landfill site.

In the study, sludge samples were taken from the dewatering unit to determine the physico-chemical properties (see Table 5.14). The pH value of the sludge was around 7.95. In literature, pH value of the sewage sludge is stated as generally in range of 7 to 8 unless lime is added during the wastewater treatment process (Epstein, 2003). Here, the pH of the fermentation industry sludge has shown neutral characteristics and thus make available it for land uses. High salinity (67 ppm) was measured in the sludge samples as an average. Dry solids were reached to 19.2% by dewatering unit. In literature, typical dry matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. However, presently, sludge generated in the plant has been deposited in the landfill site. Dry matter content is one of the principal criteria for the reception of the sludge to the landfill site. The sludge has to have dry matter content greater than 35% (SWCR, 1991). Therefore, performance of the dewatering units may be improved considering the landfill reception standards. Among the examined industries, the highest organic content was found in the fermentation industry sludge (i.e. 82%). In addition, the organic carbon content of the sludge was determined as 47%. In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land and improve the soil characteristics.

Table 5.13 Physico-chemical properties of the fermentation industry sludge

Parameters	Unit	Samples	
		I	II
pH		8.73	7.18
Salinity	ppm	80.19	53.81
Dry Solids	%	22.85	15.48
Moisture Content	%	77.15	84.52
Organic Matter	%	92.77	71.41
Organic Carbon	%	48.62	45.67
Total Nitrogen	mg/kg	10.6	12.6
Phosphorus	mg/kg	4.3	12.72
Potassium	mg/kg	3787	3873
Iron	mg/kg	275.9	1211
Magnesium	mg/kg	721.0	5260
Calcium	mg/kg	20160	19330
Sodium	mg/kg	2865	2512

The average N content is reported as 38.4 g/kg DS in the literature (Vesilind and Spinosa, 2001). Similarly, total nitrogen of sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). Therefore, since nitrogen content of the fermentation industry sludge was measured as 11.2 mg/kg, nitrogen deficiency is observed and thus fertilizing capability is limited for agricultural uses. On the other hand, relatively lower and varied phosphorus was reported in the samples (see Table 5.1). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

Potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). Potassium content was measured as 3830 mg/kg, and thus it can be concluded that nutrient levels in fermentation industry sludge samples can fulfill the requirements for use in agricultural fields.

In general, fermentation industry sludge was deficient in terms of secondary plant nutrients. Calcium content of the sludge was measured as 19.7 g/kg DS (average). In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. When literature values compared with the results one may conclude that relatively lower calcium content was measured in the fermentation industry sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the examined industry sludge was around 3 g/kg, thus magnesium content in sludge was insufficient for agricultural uses. Nutrient deficiency was also observed in terms of sodium. Measured sodium concentration was 2688 mg/kg while 5700 mg Na/kg is attained in sewage sludge (Sommers, 1977). Finally, iron was also insufficient for agricultural uses. Because, measured iron content was 743.4 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Heavy metal concentrations of the fermentation industry sludge are presented in Table 5.14 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.14, heavy metals concentrations in the sludge are much lower than the tolerance levels.

In the experiments, fermentation industry sludge samples were analyzed to determine the concentrations of fecal coliform and total coliform bacteria. The values of fecal coliform and total coliform densities of dewatered sludge are given in Table 5.15. Fecal coliform densities were determined as 1.9 million MPN/g DS. Regarding to the coliform parameter, the fermentation industry sludge is characterized as Class B and should be stabilized before the land use.

Table 5.14 Heavy metal concentrations of the fermentation sludge

Sample	Heavy Metals – (mg/kg)					
	Cu	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
Sample I	5.986	26.51	0.294	13.06	1.996	5.788
Sample II	18.89	255.9	1.367	6.878	9.011	19,72
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

Table 5.15 Fecal and total coliform densities of the fermentation industry sludge

Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
Sample I	$1.8*10^6$	$3.6*10^6$
Sample II	$2.0*10^6$	$4.0*10^6$

5.1.6 The Non Alcoholic Beverage Industry Treatment Plant Sludge

5.1.6.1 Process Description

The wastewater is generated from sweetener preparation, carbonate addition, bottle washing, and filling of beverages to the bottles. The wastewater is characterized by high alkalinity due to the alkali washing; moderate organic matter content and low nutrient concentrations. The wastewater treatment plant consists of equalization tank, neutralization tank, biologic treatment unit (extended aerated activated sludge process), final sedimentation tank, and chlorine dosages unit. Sludge taken from the bottom of the final sedimentation tank is pumped to the sludge dewatering unit. Drying beds are used to dewater the sludge. The physico-chemical properties of the non-alcoholic beverage production industry sludges are presented in Table 5.16.

The pH value of the sludge was around 7.87. Here, the pH of the meat processing sludge has shown neutral characteristics and thus make available it for land uses. Relatively lower salinity (34.42 ppm) was obtained for beverage industry sludges. Dry matter content of the sludge samples was about 25.6%. In literature, typical dry

matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. For the beverage industry, organic matter content of the sludge was measured as 83.8% that can be considered as quite high. In addition, the organic carbon content of the sludge was determined as 43.8% (as an average). In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

When the measured N concentrations compared with the literature values one may conclude that the sludge was deficient in terms of N and thus fertilizing capability is limited for agricultural uses. On the other hand, phosphorus content was relatively higher than nitrogen content (i.e. ~ 19 mgP/kg). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

Secondary plant nutrients were also measured in the sludge samples. Among them, potassium which is considered as one of the essential nutrient was measured as 1367 mg/kg. Potassium content of the sewage sludge is reported as 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS in the literature (Vesilind and Spinosa, 2001). Therefore, relatively higher potassium content may be valuable for land applications. Among the iron, magnesium, and calcium elements, the highest concentration was measured in calcium (i.e. 19269 mg/kg). In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. However, when literature values compared with the results one may conclude that relatively lower calcium content was measured in the beverage industry sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the beverage industry sludge was around 2653 mg/kg DS, thus magnesium content in sludge was insufficient for agricultural uses. Nutrient deficiency was also observed in terms of sodium. Measured sodium

concentration was 1601 mg/kg while 5700 mg Na/kg is attained in sewage sludge (Sommers, 1977). Iron was also insufficient for agricultural uses. Because, measured iron content of the beverage industry sludge was 1812 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Table 5.16 Physico-chemical properties of the beverage industry sludge

Parameters	**Unit**	**Samples**	
		I	**II**
pH		7.83	7.92
Salinity	ppm	33.76	35.08
Dry Solids	%	20.73	30.58
Moisture Content	%	79.27	69.42
Organic Matter	%	85.79	81.92
Organic Carbon	%	45.93	41.80
Total Nitrogen	mg/kg	7.8	5.9
Phosphorus	mg/kg	11.77	26.74
Potassium	mg/kg	2360	374.6
Iron	mg/kg	2946	677.4
Magnesium	mg/kg	2630	2676
Calcium	mg/kg	32100	6438
Sofium	mg/kg	1377	1825

Heavy metal concentrations of the beverage industry sludge are presented in Table 5.18 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen the tolerance levels.

Table 5.18 Heavy metal concentrations of the beverage industry sludge

Sample	Heavy Metals – (mg/kg)					
	Cu	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
Sample I	31.0	368.64	2	65.488	42	27.928
Sample II	10.90	115.8	0.855	9.880	20.39	4.699
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

In the experiments, beverage industry sludge samples were analyzed to determine the fecal and total coliform bacteria densities and the results are presented in the Table 5.18. Fecal coliform densities were determined as 1.68 million MPN/g DS (as average). Regarding to the coliform parameter, the beverage industry sludge is characterized as Class B and should be stabilized before the land use.

Table 5.19 Fecal and total coliform densities of the beverage industry sludge

Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
Sample I	$1.4*10^6$	$2.8*10^6$
Sample II	$1.8*10^6$	$3.0*10^6$

5.1.7 Municipal Wastewater Treatment Plant Sludge

5.1.7.1 Process Description

In the study, sludge samples were also taken from a municipal wastewater treatment plant to compare the characteristics of the sludge. The capacity of the treatment plant is 7 m^3/s. Treatment facility includes screens, grit chambers, primary sedimentation tanks, and biological treatment designed according to the nitrogen and phosphorus removal principles from the wastewater. Sludge taken from the bottom of the primary and final settling tanks is introduced to the mechanical thickeners; then stabilized with lime addition and finally dewatered in the belt presses.

Dewatered sludge is stabilized by lime addition and a product that is harmless to the nature and environment is obtained. Pilot scale studies have been also conducted using sewage sludge obtained from the treatment facility. Various vegetables and fruits such as spinach, broccoli, cabbage, cauliflower, tomato, eggplant, pepper and corn are grown with sludge in both summer and winter seasons. In Table 5.19, the physico-chemical properties of the sewage sludge are presented.

Although the sludge is stabilized with lime the pH value was measured as 8.03. Salinity of the sludge was 33.7 ppm due to salt water introduction to the collection system, thus wastewater is contaminated with salt. Dry matter content of the sludge samples was around 20%. In literature, typical dry matter contents of various biosolid's processes are reported as liquid (2-12%), dewatered (12-30%), and dried or composted (50%). Therefore, the solid content of the sludge has shown that the sludge can be applied to the land. However, presently, sludge generated in the plant has been deposited in the landfill site. Dry matter content is one of the principal criteria for the reception of the sludge to the landfill site. The sludge has to have dry matter content greater than 35% (SWCR, 1991). Therefore, performance of the dewatering units may be improved considering the landfill reception standards. The organic content of sewage sludge varies, depending on the quality of the wastewater and extent of treatment. The, organic matter content of the sludge was measured as 86% that can be considered as quite high. In addition, the organic carbon content of the sludge was determined as 46%. In literature, organic carbon ratio of the sewage sludge is reported as in range of 6.5-48% for aerobic treatment systems (Sommers, 1977). Hence, regarding the carbon content, sludge obtained from examined industry can preferably be applied on land.

The results of an extensive survey on plant nutrients in sewage sludge are reported by Vesilind and Spinosa (2001). According to their study, the fertilizing value of 6000 analyzed sewage sludge samples is varied between 0.1-246 g/kg DS. The average N content is 38.4 g/kg DS in the same literature. Similarly, total nitrogen of sewage sludge obtained from aerobic treatment processes is given as 4.9% (average) in US EPA (1995). However, comparative evaluation of those references and

experimental results stated that sludge obtained from the treatment facility was deficient in terms of nitrogen. Phosphorus content was relatively higher than nitrogen content (i.e. ~ 26 mgP/kg). For sewage sludge, phosphorus content is ranged in 1.1-5.5% (USEPA, 1995). According to the Spinosa and Vesilind (2001), phosphorus content (as P_2O_5) is varied from 0.2 to 344 g/kg DS. Similarly to nitrogen parameter, sludge is poor in terms of phosphorus.

Table 5.19 Physico-chemical properties of the sewage sludge

Parameters	**Unit**	**Sewage Sample**
pH		8.03
Salinity	ppm	33.76
Dry Solids	%	20.73
Moisture Content	%	79.24
Organic Matter	%	85.79
Organic Carbon	%	45.93
Total Nitrogen	mg/kg	7.8
Phosphorus	mg/kg	25.88
Potassium	mg/kg	5274
Iron	mg/kg	4570
Magnesium	mg/kg	3614
Calcium	mg/kg	10250
Sodium	mg/kg	3179

In general, sewage sludge contains low potassium (K). In literature, potassium content of the sewage sludge is reported as an average 0.46% (USEPA, 1995). Potassium content (as K_2O) is also varied between 0.1-95 g/kg DS according to the Vesilind and Spinosa (2001). In this study, potassium content was measured as 5.27 g/kg that can be accepted in the range presented in the literature.

In general, sewage sludge was deficient in terms of secondary plant nutrients. Calcium content of the sludge was measured as 10.25 g/kg DS. In literature, Ca content is given as 3.3% (USEPA, 1995) and 73.7 g/kg DS as CaO. When literature values compared with the results one may conclude that relatively lower calcium content was measured in the examined sewage sludge. Magnesium (MgO) can be found in the sewage sludge up to 122 g/kg DS. However, magnesium content of the sewage sludge around 3614 mg/kg DS, thus magnesium content in sludge was insufficient for agricultural uses. On the other hand, sodium content of the sludge was measured as 3179 mg/kg which may be accepted as adequate for land uses. Iron was also insufficient in the sludge because it was measured as 5274 mg/kg while it should be 13000 mg/kg in the literature (Sommers, 1977).

Heavy metal concentrations of the sewage sludge of the examined municipal wastewater treatment plant are presented in Table 5.20 together with the limits given in the Turkish Regulation on Soil Pollution Control (SPCR, 2001). As can be seen from the Table 5.20, heavy metals concentrations in the sludge are much lower than the tolerance levels.

Table 5.20 Heavy metal concentrations of the sewage sludge

Sample	**Heavy Metals – (mg/kg)**					
	Cu	**Zn**	**Cd**	**Cr**	**Pb**	**Ni**
Sample I	43.66	338.3	0.869	94.06	10.95	53.91
SPCR limits	1750	4000	40	1200	1200	400

Soil Pollution Control Regulations (SPCR)

In the experiment, sewage sludge sample was analyzed to determine the concentrations of fecal and total coliform bacteria and the results are presented in the Table 5.21. Fecal coliform density was determined as 2.4 million MPN/g DS while total coliform density was 4.8 million MPN/g DS. Regarding to the coliform parameter, the sewage sludge is classified as B and should be stabilized before the land use.

Table 5.21 Fecal and total coliform densities of the sewage sludge

Sample	Fecal coliform (MPN/g DS)	Total coliform (MPN/g DS)
Sample I	$1.4*10^6$	$2.8*10^6$

5.2 Treatment Studies

In the study, treatment studies were performed in order to improve sludge characteristics for land application. In general, sludge generated from the agro-industries treatment facilities was deficient in terms of plant nutrients especially nitrogen, phosphorus and potassium, but rich in organic matter. Besides, heavy metal concentrations detected in the sludge samples were lower than the tolerance limits set by the MoEF. Regarding the bacterial contamination, coliform densities were higher than 10^3 MPN/g DS thus improvement of the sludge characteristics in terms of coliform was required to obtain Class B or Class A biosolid. In order to improve the microbiologic quality chemical stabilization, thermal stabilization and combination of these methods were performed separately. Treatment studies were carried out using meat processing industry due to its high coliform densities. The results of the treatability studies are presented in the following sections.

5.2.1 Chemical Stabilization

Data derived from Andreadakis (1989) and Yurtsever (2005) was used to determine the lime (CaO) dose. Andreadakis (1989) reported that a substantial reduction of pathogens can be achieved for a dose of 2%. However, a reduction of pathogens over prolonged periods (over 1 day) may require a dose of over 4% CaO. Similarly, Yurtsever (2005) stated that a dose of 2% quicklime was enough to meet the US EPA criterion. However, considering the pH requirement (keeping pH over 12 during 24 hours) lime dosage was recommended as 3% for the practices. Therefore, in this study, lime dose was used as 3% to obtain sufficient disinfection and meet Class B or conventional standard biosolids referred to EPA and EU regulations.

Since pH is an important parameter for pathogen reduction and keeping the pH at least 12 for 24 hours is reqired in the regulations, pH values were observed through the following frequencies:

- just after liming, at time 0
- 2 hours later
- 6 hours later
- 24 hours later
- 72 hours later

Fecal and total coliform densities were measured for 3% CaO dose and variation of the coliforms with time was investigated. Dry matter content of the sludge was determined, too. The results are presented in Table 5.22.

Table 5.22 Results of the chemical stabilization study

Parameters	**Lime Dose (3%)**			
	I	**II**	**III**	**IV**
pH				
t = 0	11.40	12.04	12.25	12,40
t= 2h	11.79	12.08	12.43	12.63
t = 6h	12.08	12.11	12.24	12.28
t = 24h	12.02	12.08	12.16	12.29
t = 72h	12.4	12.48	12.56	12.68
Total Coliform (MPN/g DS)				
t = 0	2200000	2200000	2200000	2200000
t= 2h	281000	350000	231000	382000
t = 6h	41000	37000	51000	46000
t = 24h	30000	29000	39000	36000
t = 72h	3790	3130	2880	2300
Fecal Coliform (MPN/g DS)				
t = 0	1100000	1100000	1100000	1100000
t= 2h	140000	230000	130000	160000
t = 6h	20000	25000	19000	24000
t = 24h	15000	19000	16000	17000
t = 72h	1900	1440	1520	1200
Dry Solid (%)	21	16	25	27
Moisture Content (%)	79	84	75	73

The pH variation throughout 72 hour is illustrated in Figure 5.1. The pH value of raw sludge was around 7.2. The results were shown that 3% lime dosage was sufficient to keep pH over 12 during 24 hours. The dry matter contents of raw dewatered sludge was 18%. After lime addition, dry matter content of the biosolids increased to 22.2% due to the increasing of the solid matter content. Reduction of the fecal and total coliforms throughout 72 hours was shown in Figure 5.2 and 5.3. Fecal coliforms were reduced from $1.1*10^6$ MPN/g DS to $1.5*10^3$ at the end of 72 hours. Total coliforms were measured $1.2*10^4$ MPN/g DS at the end of the 72 hours.

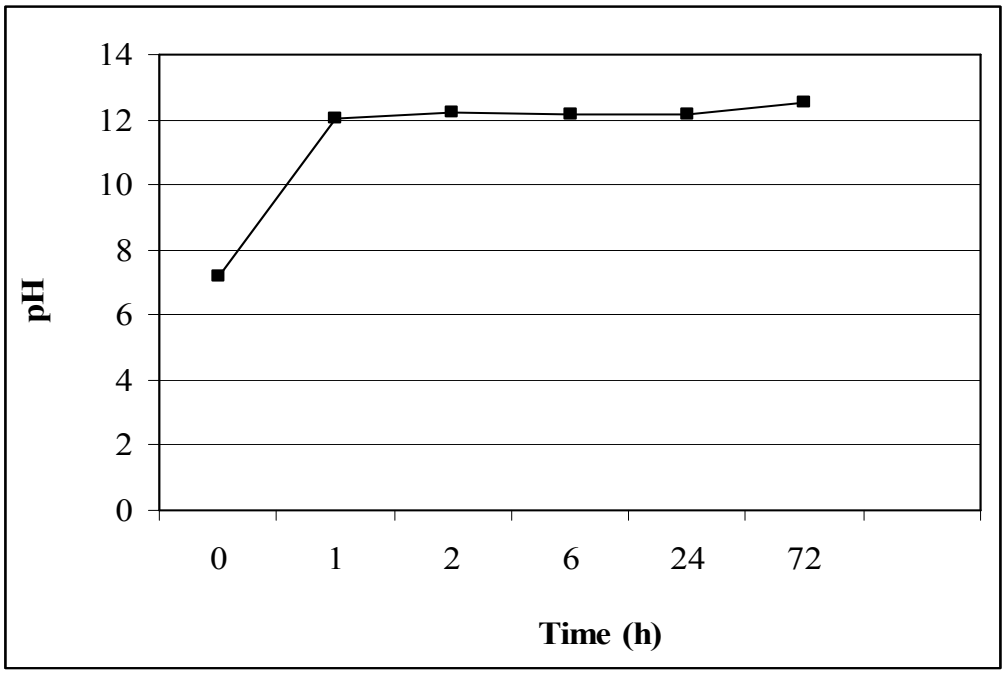

Figure 5.1 pH variation after lime addition with respect to time

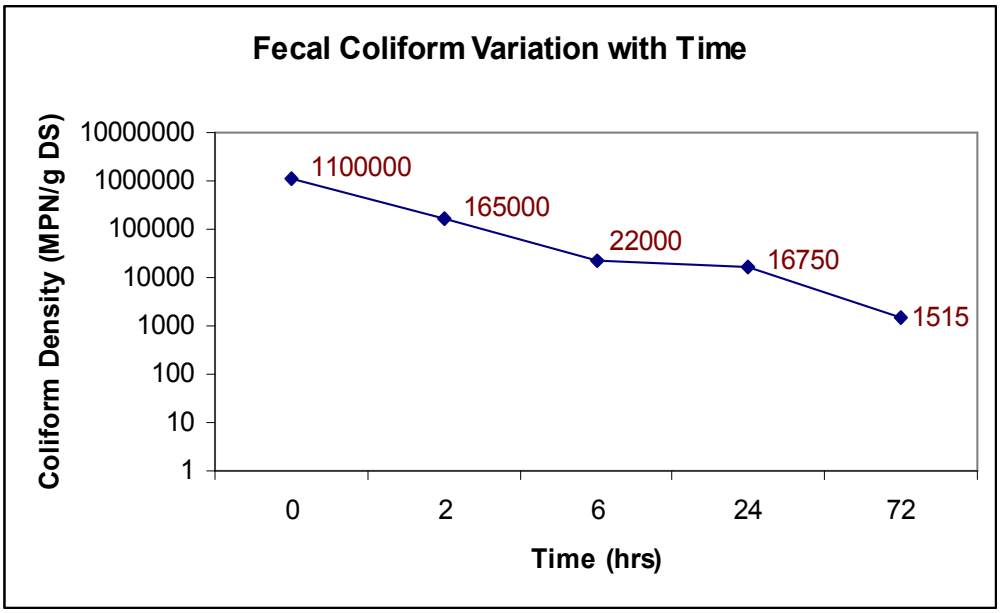

Figure 5.2 Fecal coliform variations with respect to time

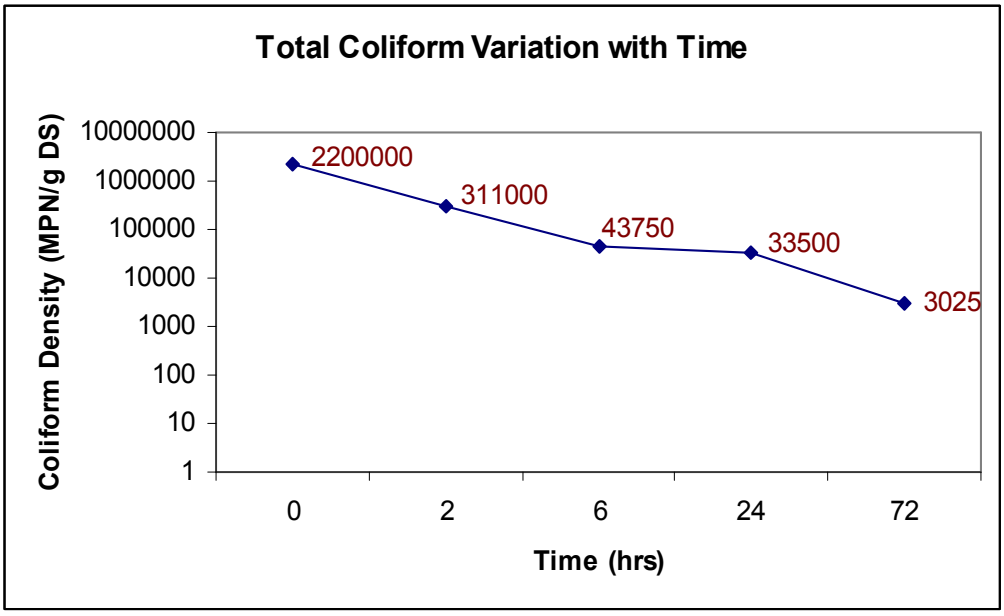

Figure 5.3 Total coliform variations with respect to time

5.2.2 Thermal Stabilization

In the experiments, specific time-temperature regimes to reduce pathogens in sludge samples under US EPA Class A biosolid pathogen requirements were achieved. In this approach, the heating time necessary at a particular temperature to

reduce the sludge's pathogen content to below detectable levels was investigated. Therefore, sludge was heated to a temperature of 50, 70, 180 ^{o}C throughout 120 minutes. Total and fecal coliform densities measured at various time intervals (i.e. 15 to 120 min.) are presented in Table 5.23.

Table 5.23 The effect of the thermal treatment on sludge properties

Parameters	**Applied Temperature**		
	50 ^{o}C	**70 ^{o}C**	**180 ^{o}C**
Total Coliform (MPN/g DS)			
t= 0	3800000	3800000	3800000
t=15 min	64000	35000	1800
t=30 min	58000	33000	530
t=60 min	52000	6100	260
t=120 min	3800	2700	210
Fecal Coliform (MPN/g DS)			
t= 0	1900000	1900000	1900000
t=15 min	32000	18000	900
t= 30 min	29000	16500	270
t= 60 min	26000	3050	130
t= 120 min	1900	1400	105
Dry Solid (DS, %)	15.29	13.45	10.38
Moisture Content (MC, %)	84.71	86.55	89.62

The effect of the temperature on pathogen reduction, and the optimal time to fulfill Class A biosolid requirement were investigated in this study. The results are schematically shown in Figures 5.4-5.6 for total coliforms and in Figures 5.7-5.9 for fecal coliforms. In general, lower temperatures (i.e. 50 and 70°C) were insufficient to meet the Class A biosolid requirements. For the temperature of 50 ^{o}C, total coliform was reduced from $3.8*10^{6}$ MPN/g DS to 3800 at the end of the 2 hours (see Fig. 5.4).

As can be seen in Figure 5.5 fecal coliforms were reduced from $1.9*10^6$ MPN/g DS to 1900 at the same temperature and time. When heating was increased to 70 °C, total coliforms were reduced to 2700 MPN/g DS within 2 hours while fecal coliforms were decreased to 1400 MPN/g DS.

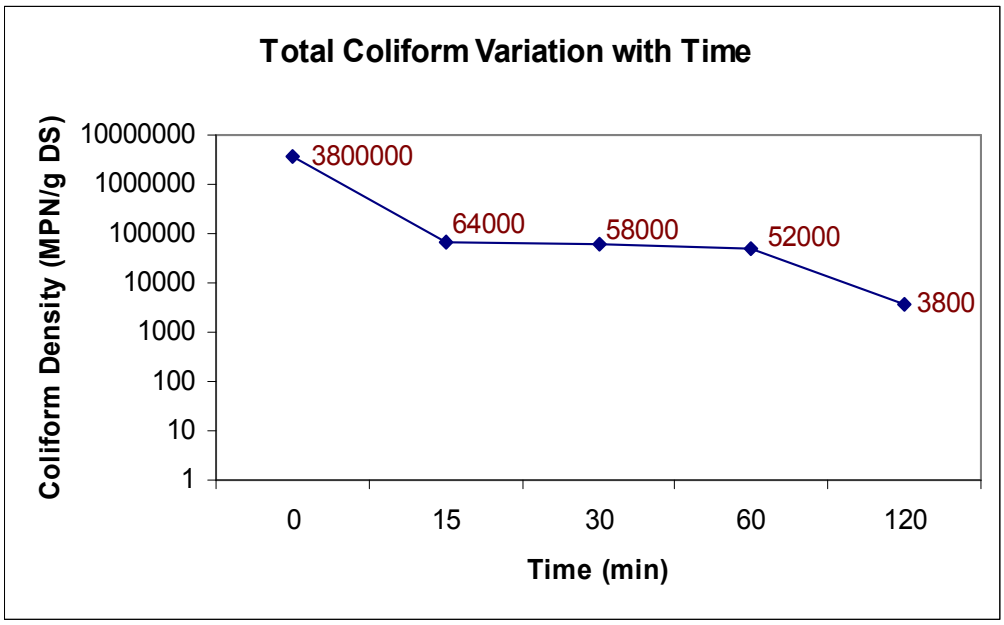

Figure 5.4 Total coliform variation for the temperature of 50 °C

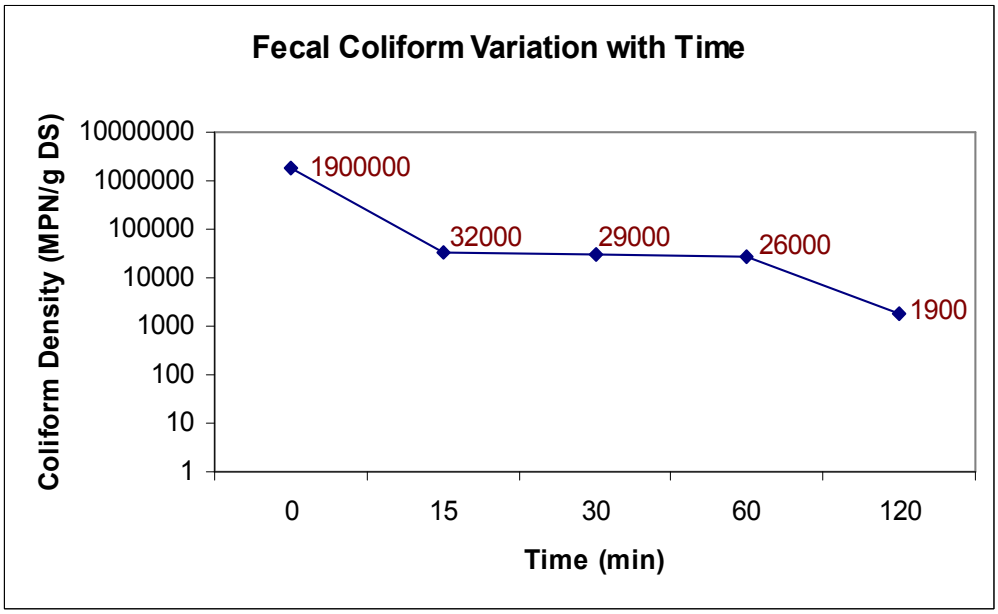

Figure 5.5 Fecal coliform variation for the temperature of 50 °C

Results derived from the Table 5.22 for the temperature of 70 ^{o}C are presented in Tables 5.6 and 5.7. On the other hand, when sludge was heated to a temperature of 180°C, total coliforms were decreased from $3.8*10^{6}$ MPN/g DS to 530 within 30 minutes (see Fig. 5.7). Similarly, fecal coliforms was reduced to 900 MPN/g DS in 15 minutes. Thus, examination of the data given in Table 5.22 and Figures 5.4-5.9 was shown that pathogen reduction was affected from increasing temperature. Lower temperatures, i.e. 50 and 70 ^{o}C were not enough to reduce the pathogen levels below 1000 MPN/g DS (i.e. Class A biosolid). On the other hand, elevated temperature was resulted in higher pathogen reduction in promptly. The results indicated that the high temperature thermal stabilization (180 ^{o}C) can fulfill the US EPA Class A Pathogen requirements.

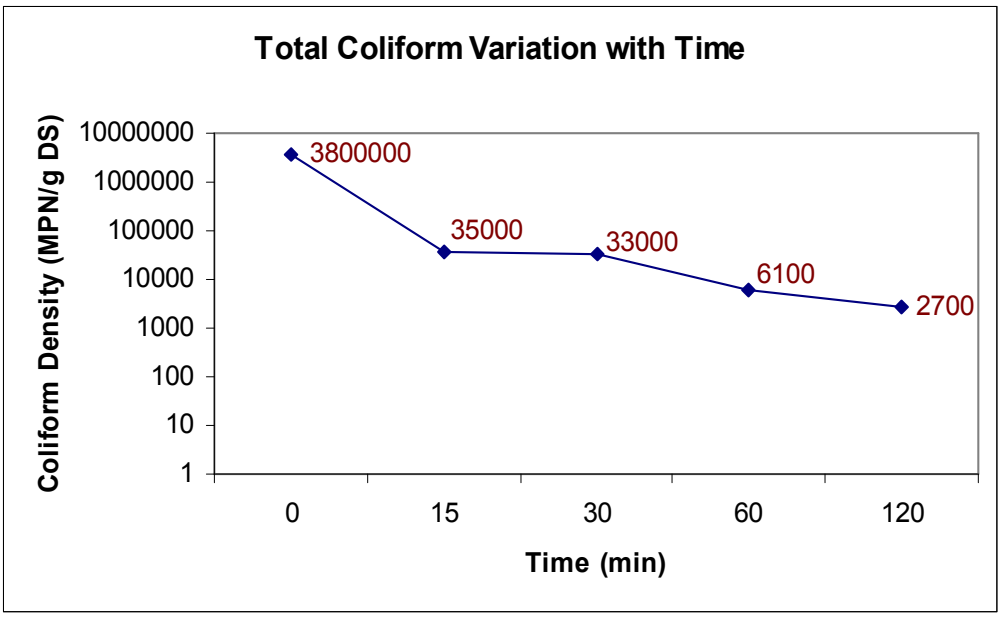

Figure 5.6 Total coliform variation for the temperature of 70 ^{o}C

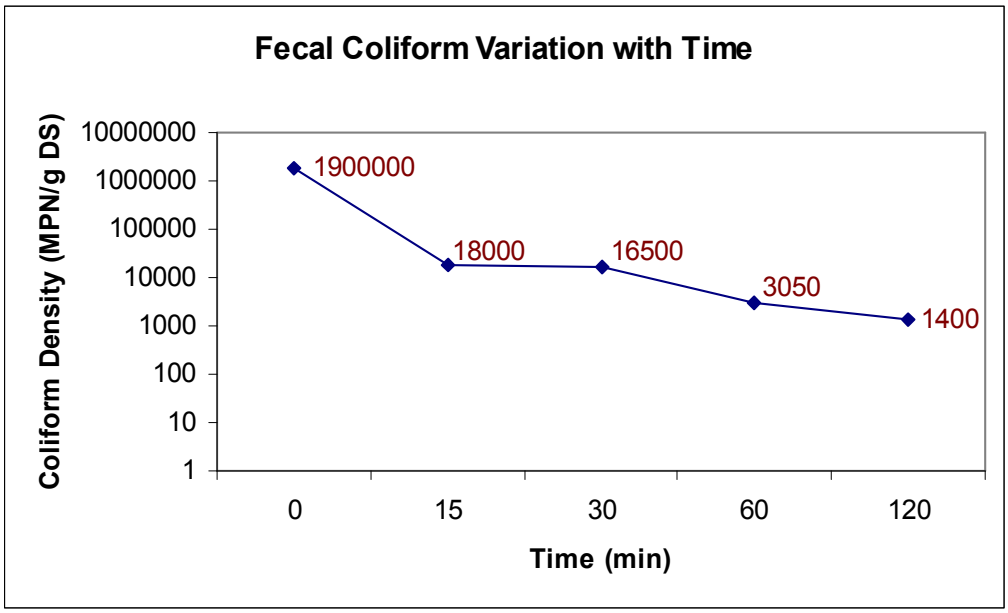

Figure 5.7 Fecal coliform variation for the temperature of 70 ^{o}C

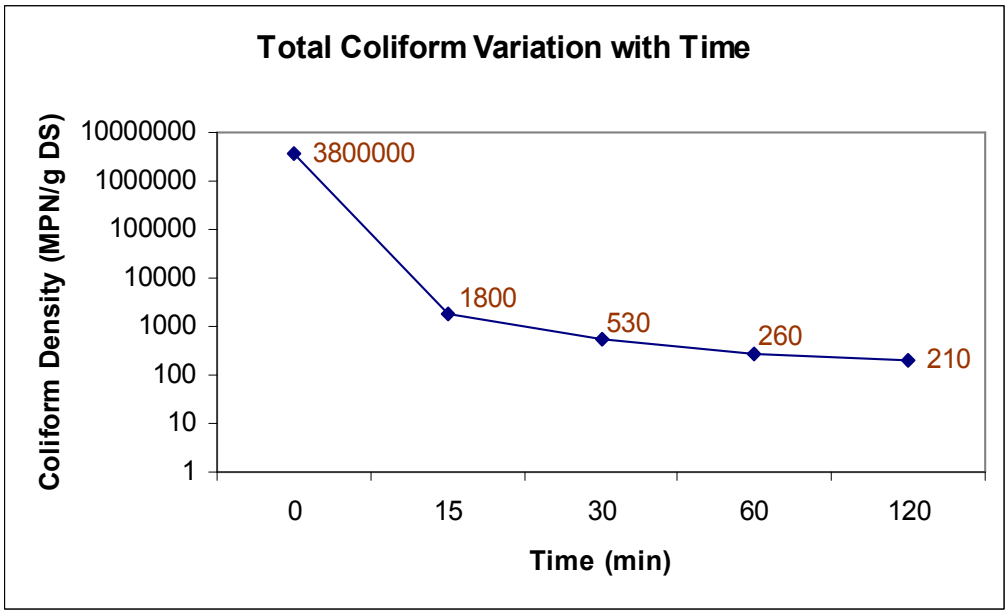

Figure 5.8 Total coliform variation for the temperature of 180 ^{o}C

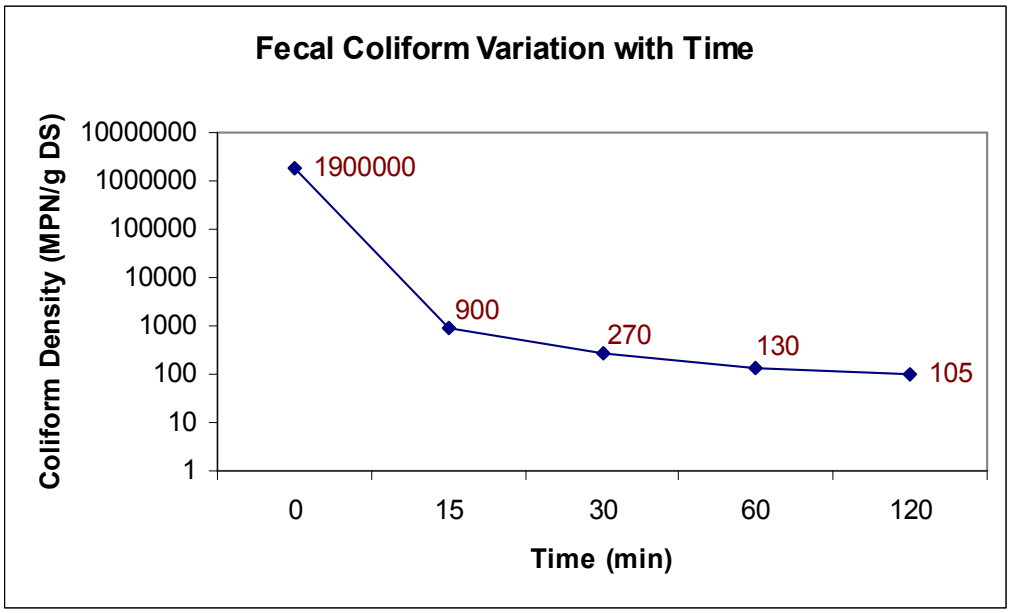

Figure 5.9 Fecal coliform variation for the temperature of 180 ^{o}C

5.2.3 Chemical + Thermal Stabilization

Treatment of the sludge in the high pH (>12 for more than 72 hours) and high temperature (above 50°C) was investigated as last alternative. Sludge chemically stabilized as first; then heated at temperatures of 50, 70 and 180°C. Fecal and total coliforms were measured at certain time intervals. Results obtained from high pH-high temperature process are presented in Figures 5.10-5.15.

Sludge was chemically stabilized with lime addition (3% CaO) and then heated to a temperature of 50°C as first. Pathogen reduction was observed throughout 120 minutes and data derived from these experiments are processed in Figures 5.10 and 5.11 for total and fecal coliforms, respectively. Total coliforms of chemically stabilized sludge were decreased from $3.4*10^{6}$ MPN/g DS to 4100 MPN/g DS at the end of the 30 minutes after heating. At the end of the 60 minutes, measured coliform densities were 879 MPN per gram dry solids (as an average). Similarly, fecal coliforms were decreased from $1.7*10^{6}$ MPN/g DS to 2000 MPN/g DS within 30 minutes. The results stated that prolonged heating periods were necessary in order to fulfill Class A biosolid requirements (i.e < 1000 MPN/g DS). Thus, fecal coliforms were reached to 440 at the end of the 60 minutes. The results indicated that the high

pH (> 12) can considerably reduce the heating time required for an effective pathogen reduction.

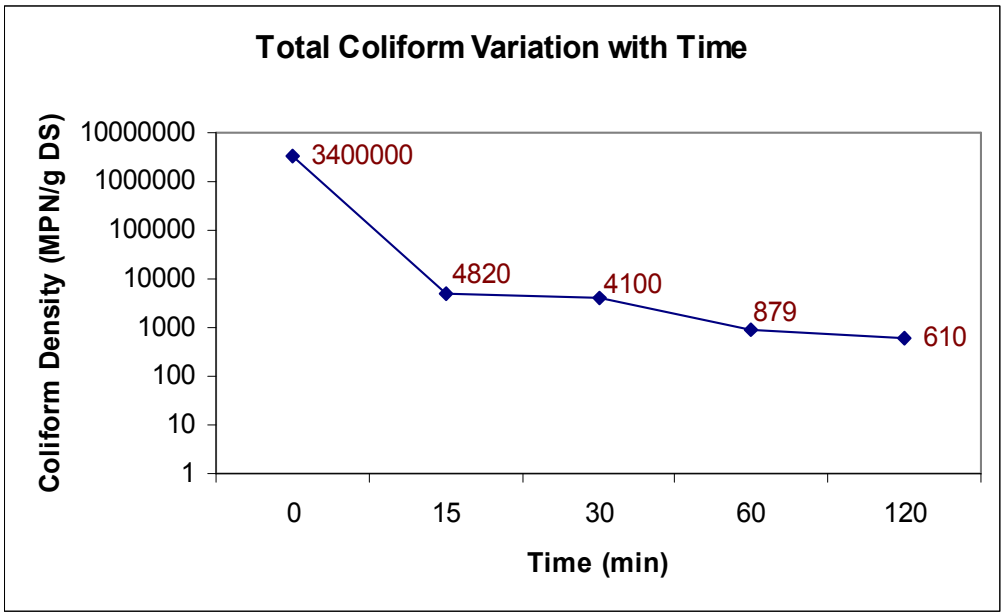

Figure 5.10 Total coliform variation of the chemically stabilized (3% CaO) and thermally treated (50 ^{o}C) sludge

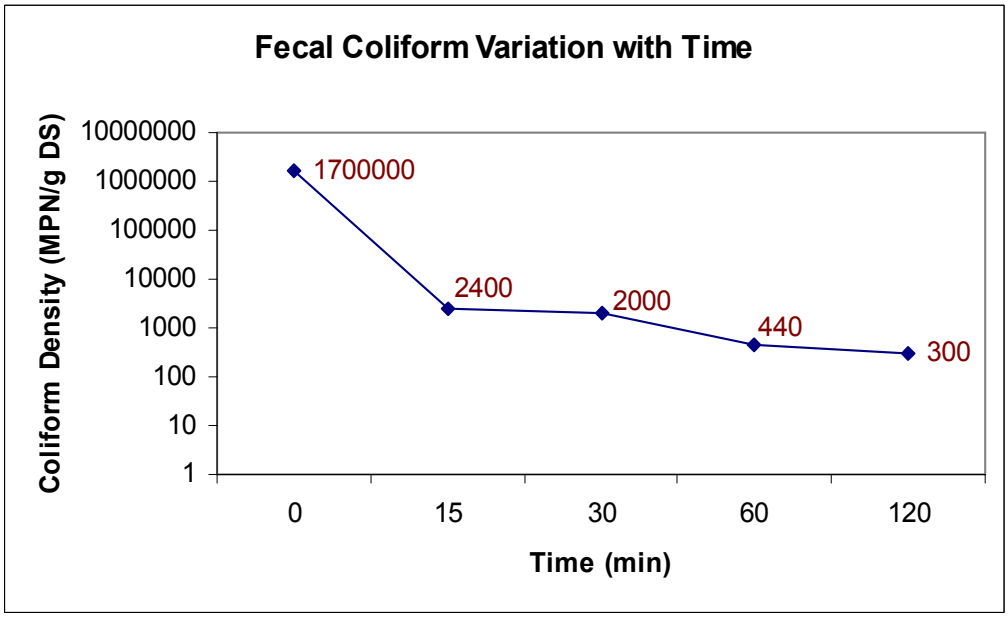

Figure 5.11 Fecal coliform variation of the chemically stabilized (3% CaO) and thermally treated (50 ^{o}C) sludge

Secondly, sludge was chemically stabilized with lime addition (3% CaO) and then heated to a temperature of 70°C. Pathogen reduction was observed throughout 120 minutes and data derived from these experiments are presented in Figures 5.12 and 5.13 for total and fecal coliforms, respectively. Total coliforms of chemically stabilized sludge were decreased from $3.4*10^6$ MPN/g DS to 3500 MPN/g DS at the end of the 15 minutes after heating. At the end of the 30 minutes, measured coliform densities were 920 MPN per gram dry solids (as an average). Similarly, fecal coliforms were decreased from $1.7*10^6$ MPN/g DS to 1750 MPN/g DS within 15 minutes. The fecal coliforms were reached to 460 at the end of the 30 minutes. The results indicated that the high pH (> 12) can considerably reduce the heating time required for an effective pathogen reduction. The results stated that 30 minutes heating time was necessary in order to fulfill Class A biosolid requirements (i.e < 1000 MPN/g DS) for chemically stabilized sludge.

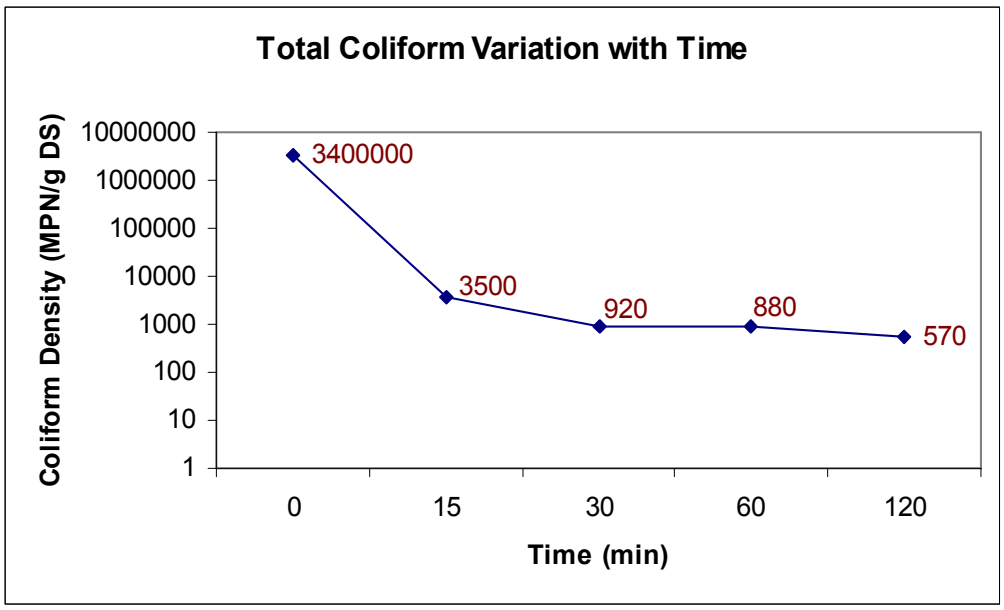

Figure 5.12 Total coliform variation of the chemically stabilized (3% CaO) and thermally treated (70 ^oC) sludge

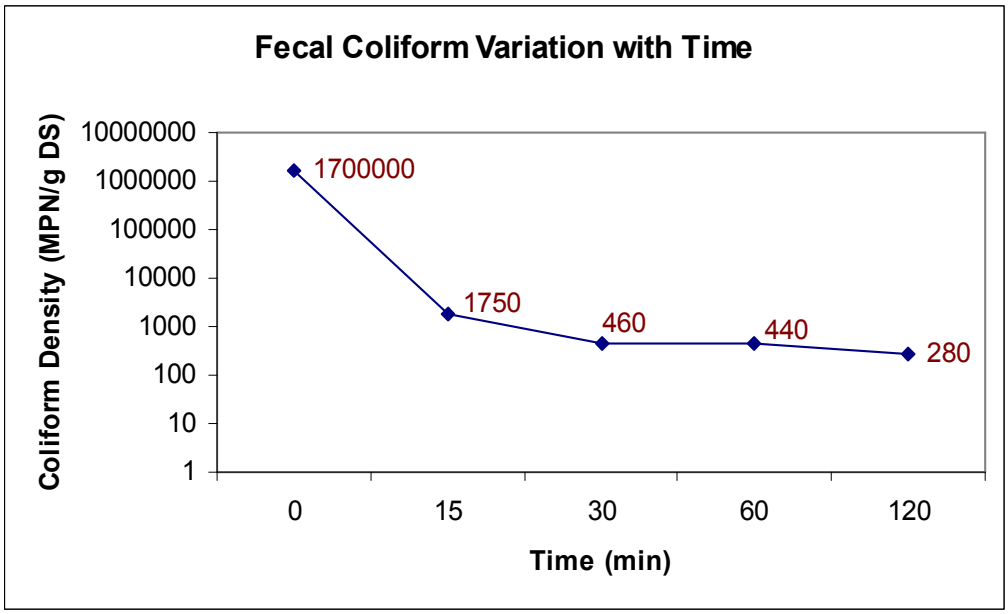

Figure 5.13 Fecal coliform variation of the chemically stabilized (3% CaO) and thermally treated (70 ^{o}C) sludge

As a last alternative, sludge was chemically stabilized with lime addition (3% CaO) and then heated to a temperature of 180°C. Pathogen reduction was observed throughout 120 minutes and data derived from these experiments are presented in Figures 5.14 and 5.15 for total and fecal coliforms, respectively. Total coliforms of chemically stabilized sludge were decreased from $3.4*10^6$ MPN/g DS to 670 MPN/g DS within 10 minutes after heating. At the end of the 30 minutes, measured coliform densities were 490 MPN per gram dry solids. Thus, for 180°C, prolonged heating times were resulted insignificant coliform reductions. Similarly, fecal coliforms were decreased from $1.7*10^6$ MPN/g DS to 340 MPN/g DS within 10 minutes. The results indicated that the high pH (> 12) and high temperature (T > 50°C) can considerably reduce the heating time required for an effective pathogen reduction. The results stated that 10 minutes heating time was necessary in order to fulfill Class A biosolid requirements (i.e < 1000 MPN/g DS) for chemically stabilized sludge.

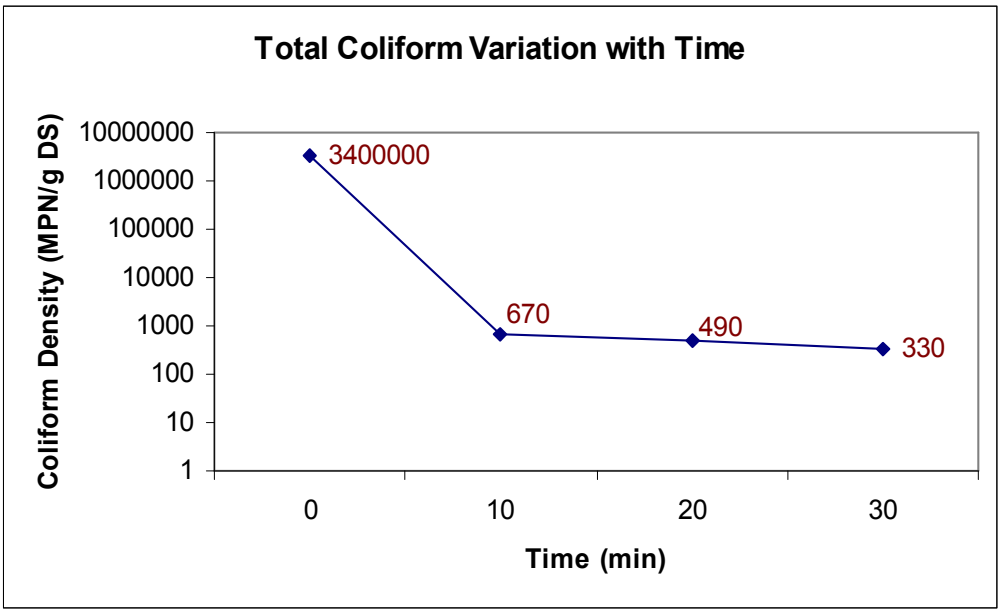

Figure 5.14 Total coliform variation of the chemically stabilized (3% CaO) and thermally treated (180 ^{o}C) sludge

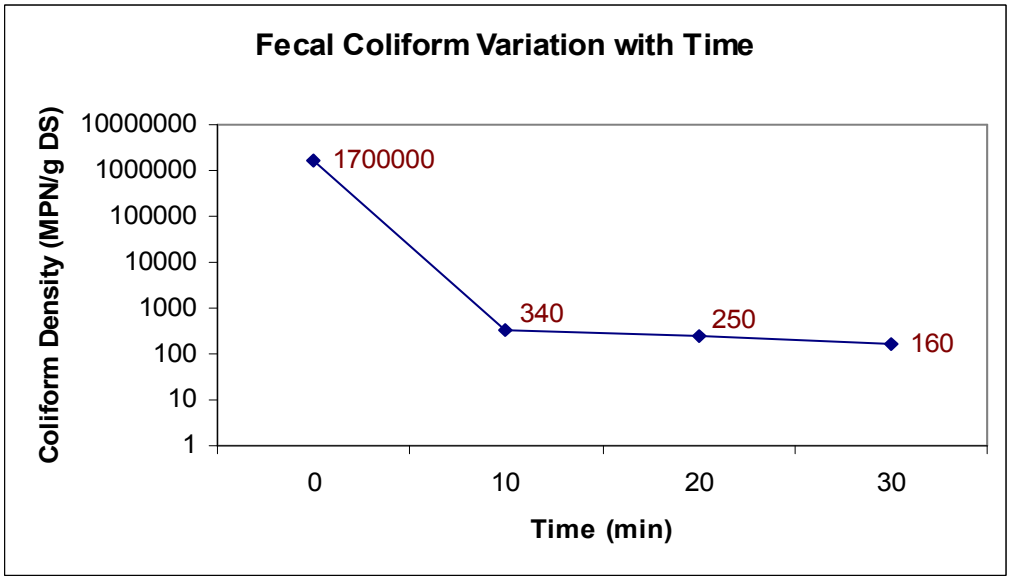

Figure 5.15 Fecal coliform variation of the chemically stabilized (3% CaO) and thermally treated (180 ^{o}C) sludge

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The sludge is final product of any wastewater treatment process and generally considered as a matter that should be disposed properly. Since sludge contains certain elements that are useful for the agricultural production and reflects no detrimental character, it may deserve particular interest especially for agro-industries. This report outlines a sustainable, financially feasible, and effective sludge management strategy especially for agro-industries. Land application is an ideal sludge disposal method for agro-industries because the factories are generally surrounded by an agricultural land and, as a result, the nutrient rich sludge can be easily and cheaply transported to the crops. Furthermore, this method minimizes costs by eliminating the need for landfill space for the sludge and farmers can reduce costs by supplementing chemical fertilizers with sludge. These financial benefits are particularly important and increase the feasibility of the project for the industries.

There are worries that sludge as a fertilizer might be harmful for the agricultural land but most people agree that sludge should be considered to be a valuable resource for the future as a fertilizer and soil improver. The quality of the sludge can be improved with control strategies for pollutants by the stabilization techniques. In this study, all experimental research aimed to investigate the characteristics of the agro-industry sludge; to determine the quality parameter exceeding the limits and improve the sludge quality. The following conclusions were derived:

- Sludge pH value was generally in the range of 7-8 except dairy industry. Since lime stabilization was applied before dewatering, higher pH value was measured in the dairy sludge. Although moderate pH values support the agricultural uses, regulations regarding to the pathogens was only satisfied by minimum 3% lime dose for chemical stabilization.

- In general, heavy metal concentrations were relatively low when compared with the allowable limits. However, excessive amounts of certain heavy metals (e.g. Cr, Pb, Ni and Cu) that can accumulate in plant tissue and may pose a risk to human health when transferred to the food chain were determined in the fermentation and distillery industries.
- Sludges originated from agro-industries were not sufficient in terms of plant nutrients (such as nitrogen, phosphorus and potassium). Thus, supplemental fertilizer addition should be required for agricultural applications. On the other hand, higher organic matter contents were measured in sludge samples. Consequently, results from this study demonstrated that the sludge taken from the agro-industries can be used as a partial substitute of chemical fertilizer and as a soil conditioner.
- Fecal coliform densities of raw sludge were in range of $1.2*10^6$ – $2.4*10^6$ MPN/g DS. The requirement for Class B biosolid was > $2*10^6$ MPN/ g DS. Thus, sludges generated from agro-industries can be land applied however restrictions relating to crop harvesting, animal grazing, and public access should be applied to their use.
- Regarding the biosolid stabilization, 3 % (w/v) lime dose satisfied for the improvement of the sludge characteristics.
- For the thermal stabilization, in general, lower temperatures (i.e. 50 and 70°C) were insufficient to meet the Class A biosolid requirements. On the other hand, when sludge was heated to a temperature of 180°C, significant pathogen reduction was achieved sharply. The results indicated that the high temperature thermal stabilization (180 ^{o}C) can fulfill the US EPA Class A Pathogen requirements.
- Results obtained from high pH-high temperature process indicated that the high pH (> 12) can considerably reduce the heating time required for an effective pathogen reduction. When the chemically stabilized sludge was heated to a temperature of 70°C, 30 minutes heating time was necessary to fulfill Class A biosolid requirements. For the 180°C (heating temperature), 10 minutes heating time was sufficient to fulfill Class A biosolid requirements.

6.2 Recommendations for Further Studies

For further researches, the content of the study may be enlarged. The number of the industries may be increased and varied. The replications of the samplings may also be increased to obtain more reliable data. In a field study, effects of land application of biosolids on crop yield and soil quality may be investigated. So, the heavy metal accumulation in soil, crop and also groundwater may be observed. This kind of collaboration makes the use of sludge in agriculture more reliable.

Lime treatment is already well established treatment method for the pathogen reduction however other chemical treatments may be developed to improve the microbiologic quality. On the other hand, such methods are likely to increase the total volume of treated sludge with consequential problems of transport, storage and the need to increase application rates to achieve similar fertilizing value to heat-treated sludges.

At the present time one of the most cost-effective forms of sludge treatment is the use of heat (thermal treatment). In this study, operating parameter such as temperature and time were investigated. Effective temperature and time was determined considering the pathogen reductions. Moreover, the effect of the heating onto pathogen reduction can also be associated with the dry solids. Finally, other processes like irradiation may be developed in the future.

REFERENCES

Andreadakis, A. D., 1999. "*Treatment and disinfection of sludge using quicklime*" *Workshop on Problems around sludge Proceedings*, Heinrich Logenkamp, Lucamarmo, editors, pp. 31-37, 18 – 19 November, Italy.

APHA-AWWA-WEF, 1992. In Greenberg, A., Clesceri, L. S., Eaton A. D. (Eds), *Standard Methods for the Examination of Water and Wastewater*, 18 th ed., Washington, DC.

A. P. Sincero and G. A. Sincero (2003). Physical and Chemical Treatment of Water and Wastewater. IWA Publishing, London

Brown, S., and R. L. Chaney 2000. Combining by-products to achieve specific soil amendment objectives. p. 343-360. *In* J.F. Power and W.A. Dick (eds.) *Land Application of Agricultural Industrial, and Municipal By-Products*. Soil Science Society of America, Inc., Madison, WI.

Carrington, E. G., (1997). *Microbiological hazards to human contacts of land spreading of wastes*. Report CO 4293, WRc, Medmenham.

Chaney, R. L., 1980. "Health Risks Associated with Toxic Metals in Municipal Sludge." *In Sludge-14ealth Risks of Land Applicafion,* G. Bitton, B. L. Damron, G. T. Edds, and J. M. Davidson, editors, pp. 59-84. Ann Arbor, Michigan: Ann Arbor Science Publications, Inc.

Chaney, R. L., S. L. Brown, J. A. Ryan, J. G. Hallfrisch, Q. Xue, T. I. Stuczynski, and H. Compton. 2001. *Using biosolids, composts, and tailor-made biosolids mixtures in remediating urban and brownfield sites and other metal-contaminated soils p. 28* In Proc. Innovative Uses of Biosolids – A Symposium, Sept. 17-19, 2000, Chicago, IL. CD-ROM, Water Environmental Federation, Alexandria, VA.

Council Directive of 15 July 1975 on waste (75/442/EEC) (OJ L 194, 25.7.1975, p. 39)

Council for Agricultural Science and Technology (CAST), 1976. *Application of Sewage Sludge to Cropland Appraisal of Potential Hazards of the Heavy Metals to Plants and Mammals*. EPA Report No. 430/9-76-013. U. S. Environmental Protection Agency, Office of Water Program Operations, Washington.

Council Directive of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture

Dolgen, D., Alpaslan, M. N., 2000. *Treatment of industrial wastewater by SBR process: pickle and brewery industry examples*. In: Proceedings of the second International symposium on Sequencing Batch Reactor Technology, Narbonne, France, pp. 75–79.

Dolgen, D., Alpaslan, M. N., Delen, N. (2007): *Agricultural recycling of treatment-plant sludge: A case study for a vegetable-processing factory*. Journal of Environmental Management, 84, 274-281

Elliott, H., B. Dempsey, D. Hamilton, and J. Wolfe. 1990. *Land application of water treatment plant sludges: Impact and management*. American Water Works Research Foundation, Denver, CO.

Environment DG (2000) *Working Document on Sludge, 3rd draft ENV.E.3/LM.*

EPA_1 US Environmental Protection Agency. Retrieved May10, 2004 from http://www.epa.gov/owm/mtb/biosolids/index.htm

EPA_2 US Environmental Protection Agency. Retrieved May10, 2004 from http://www.epa.gov/owm/mtb/biosolids/503pe/503pe_1.pdf

EPA$_3$ US Environmental Protection Agency. Retrieved May10, 2004 from http://www.epa.gov/owm/mtb/biosolids/genqa.htm

Epstein, E., 2003, *Land Application of Sewage Sludge and Biosolids*. CRC Pres LLC, 2000 N.W. Corporate Blvd. , Boca Raton, Florida 33431, USA.

European Commission. (2001). *Disposal and Recycling Routes for Sewage Sludge- Scientific and Technical sub-component report.*

European Commission. (2001). *Disposal and Recycling Routes for Sewage Sludge- Scientific and Technical sub-component report.*

European Commission DG Environment. (2001). *Evaluation of Sludge Treatments for Pathogen Reduction – Final Report*

Farrell, J. (1974). "Overview of Sludge Handling and Disposal," in *Municipal Sludge Management* (rockville, MD: Information Transfer, Inc.)

G. K. Evanylo (1999a). *Agricultural Land Application of Biosolids in Virginia: Production and Characteristics of Biosolids*. Virginia Cooperative Extension, Publication 452 - 301.

G. K. Evanylo (1999b). "*Agricultural Land Application of Biosolids in Virginia: Managing Biosolids for Agricultural Use*". Virginia Cooperative Extension, Publication 452-303

Hanson, J. B. (1972). "*Viral contamination as Measured by Coliphages*," Duke Univ. Environmental Center Publication, Durham, NC.

J. K. Muse, C. C. Mitchell (1991). "*Land Application of Sludge*," Extension Environmental Education, Auborn University, Al 36849-5647

Lee, W. Jacobs and Delina, S. McGreary (2001). "*Utilizing Biosolids on Agricultural Land,*" Extension Bulletin, E-2781

M. B. Kirkham, Uptake of barley of water table- or surface-applied cadmium, *Soil Sci. Soc. Am. J.* 41 (1977), pp. 1125–1129

Malina, J. F., Jr., K. Ranganathan, B. P. Sagik and B. E. Moore (1975). "Polivirus Inactivation by Activated Sludge," *J. Water Poll. Control Fed.* 47:8.

Mantovi P., Baldoni G., Toderi G., (2004). Reuse of liquid, dewatered, and composting sewage sludge on agricultural land: effects of long-term application on soil and crop. *Water Research* 39, 289 – 296

Mantovi P., Baldoni G., Toderi G., (2005). Reuse of liquid, dewatered, and composting sewage sludge on agricultural land: effects of long-term application on soil and crop. *Water Research* 39, 289 – 296

McKinney, R. E., H. E. Langley and H. D. Tomlinson (1958). "Survival of *Salmonella typhosa* During Anaerobic Digestion," *Sew. Ind. Wastes* 30:12

McWhorter, D. B. (1974). "Environmental monitoring of the On-Land Disposal Site," *Proc. Conference on on-Land Disposal of Municipal Sewage Sludge by subsurface Injection* (Fort Collins, CO: Colorado State Universiry).

Palfi, A. (1973). "Survival of Enteroviruses During Anaerobic Sludge Digestion," *Proc. Sixth International Conference*, Jerusalem (Oxford and New York: Pergamon Press)

Peterson, J. R., C. Lue-Hing and D. R. Zenz (1973). "Chemical and Biological Quality of Municipal Sludge," *in Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland*, W. E. Sopper and L. T. Kardos, Eds. (University Park, PA: Pennsylvania State University Press).

Petrasek AC, Kugelman IJ, Austern BM, Pressley TA, Winslow LA, Wise RH. *Fate of toxic organic compounds in wastewater treatment plants*. Water Pollution Control Fed. 1983;55(10):1286–96.

Regulation on Solid Waste Control (RSWC), 1991. Republic of Turkey, Offical Journal 20814, dated March 14, 1991.

Regulation on Soil Pollution Control (RSPC), 2001. Republic of Turkey, Offical Journal 24609, Dated March 10, 2001.

Ronald, W. Crites and Sherwood, C. Reed (2001). "*Land Treatment Systems for Municipal and Industrial Wastes*", McGraw-Hill Companies, Inc. Newyork

Ryan, J. A., D. R. Keeney, and L. M. Walsh, 1973. *"Nitrogen Transformations and Availability of an Anaerobically Digested Sewage Sludge in Soil*." *Journal of Environmental* Quality 2:489-92.

Sommers, L., D. Nelson, J. Yahner, and J. Mannering. 1972. *Chemical composition of sewage sludge from selected Indiana cities*. Oroc. Indiana Acad. Sci. 82:424-432.

Sommers, L. E., 1977, Chemical composition of sewage sludge and analysis of their potential use as fertilizers, *J. Environ. Qual*. 6: 225-232.

Spellman, F. R. and Drinam, J. E. Stream Ecology&Self-Purification: An Introduction, 2nd ed., Technomic Publ., Lancaster PA, 2001, p.149.

Spellman, F. R., 2003. *Handbook of Water & Wastewater Treatment Plant Operations*. CRC Press, ISBN 1-56670-627-0.

Tchobanoglous, G.; Burton, F. L. & Stensel, H. D. (2003). *Wastewater Engineering Treatment and Reuse*. Metcalf & Eddy, Inc, Fourth Edition

Tata, P., Lue-Hing, C. and Knafi, G. J. (1998) Statistical evaulation of pathogen innactivation for conventional low-technology Class A biosolids processes. Proceesinds, WEF conference, Orlando, FL., 2, 105

Toprak Kirliliğinin Kontrolü Yönetmeliği (2005). 25831 Sayılı Resmi Gazete.

US EPA (1993) Standdards for the use or disposal of sewage sludge, fed. Reg. 58, 32, 40 CFR Parts 247, 403, 503. EPA, Washington DC.

US EPA (1994) A plain English guide to EPA biosolids rule EPA-83Z/R-93/003. EPA, Washington DC.

U.S. Environmental Protection Agency (USEPA), 1995. Process Design Manual. *Land Application of Sewage Sludge and Domestic Septage*. EPA-625/K-95/001, Washington, DC 20460, USA.

US EPA 1995a. Process design manual. *Land application of sewage sludge and domestic septage*. EPA/625/R-95/001. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. 144p.

US EPA 1999a. *Environmental regulation and technology. Control of pathogens and vector attraction in sewage sludge*. EPA/652/R-92/013, Revised 1999. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. 177 p.

Van Gils, H. W. (1964). "*Bacteriology of Activated Sludge*,"Research Inst. For Pub. Health Eng., Delft, Nedherlands.

Vesilind P. A., (1979). *Treatment and Disposal of Wastewater Sludges*. Ann Arbor Science Publishers Inc. Michigan, USA.

Vesilind P. A., and Spinosa L., (2001). *Sludge into Biosolids*. London: IWA Publishing.

Wild SR, Berrow ML, McGrath SP, Jones KC. *Polynuclear aromatic hydrocarbons in crops from long-term field experiments amended with sewage sludge*. Environ Pollut 1992;76:25–32.

WEF Biosolids 1998. *Colorado County lifts ban on biosolids land application*. Water Environment Federation WEF Biosolids Technical Bulletin, 4(4).

Yurtsever, D., (2005). *Use of Treatment Plant Sludges as Biosolids*. M. Sc. Graduation Thesis, Faculty of Engineering, Department of Environmental Engineering, Izmir, Turkey