Sewage Sludge Treatment: An Overview and Its Possibility in Nepal

Submitted by: Anuja Hyoju
Date: May 2, 2013

To: Dr. Bidisha Majumder
Assistant Professor
Asian University for women

In partial fulfillment of the requirements for the Bachelor of Science in Environmental Science

2013

ASIAN UNIVERSITY FOR WOMEN

ACKNOWLEDGEMENT

I would like to express my sincerest gratitude and acknowledge my senior thesis supervisor, Dr. Bidisha Majumder, Assistant Professor, Environmental Science, Asian University for Women, whose constant guidance and support helped me complete my thesis. Her knowledge and critical questions consistently helped in improving my ideas throughout the course.

I would also like to appreciate and acknowledge Miss Alexandra Marie Haugh, Staff at Writing Center, Asian University for Women. Her assistance and feedbacks were very helpful during the course of my senior thesis.

Thanks to my friends of Environment Science Major and other majors at Asian University for Women who have always been very supportive and motivating.

ABSTRACT

Globally, municipal wastewater treatment produces excessive amount of semi-solid residual products, which is also known as sludge, at different stages of its operation. Sludge comprises of organic and inorganic matter, pathogens and heavy metals. Conditioning, thickening, dewatering, thermal drying, aerobic and anaerobic digestion are sludge treatment processes adopted worldwide for its safe disposal. However, Nepal has inadequate wastewater and resulting sludge treatment facilities. The present study evaluates these sludge treatment processes with emphasis on their efficiency to reduce sludge volume. It also analyzes the energy requirement for these processes to identify a suitable solution for Nepal.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 Introduction

The primary objective of municipal wastewater treatment is safe disposal of wastewater without posing any human or environmental hazards. Over the last two decades continuous efforts have been made to improve the efficiency of the current treatment plants. However, the treatment plants have significant environmental impacts due to its high energy consumption, excess use of chemicals, emissions and sludge production (Pescod, 1992 and Garg, 2009). Along with the improvement of effluents from these plants, significant attention has also been given to the treatment of the solid waste generated by these plants (Rulkens, 2008). With the growing population and accelerating urbanization worldwide, treatment of municipal wastewater will become even more crucial environmental issue in the future. In the future along with sewage, the production of residual biosolids from these treatment plants will also increase (European Environment Agency, 2001).

In comparison to the developed countries, developing nations have less prioritized the problem of wastewater generation and its treatment. Many developing countries still lack the facilities of well engineered and functioning sewage treatment plants. Similar to most developing countries Nepal will also be facing the problems of sludge pressure in the coming years with increasing urbanization and industrialization (Shukla, Timilsina and Jha, n.d.). As a consequence, Nepal will also be facing the challenge of sludge handling which require specific management procedure and technology. Sewage sludge thus remains as a permanent waste problem that requires a suitable solution (European Environment Agency, 2001).

The existing sewerage treatment in Nepal is inadequate. The lack of treatment plants and implementation of policies allow direct disposal of municipal wastewater into the surface water bodies resulting in tremendous water pollution. The problem is more urging in urban Nepal than rural. Also, there is not much literature available on wastewater treatment and sludge disposal techniques followed in Nepal. Hence, the aims of this paper, which is based on a literature review, are 1) to characterize sewage sludge, 2) to discuss the existing sludge treatment processes and 3) to analyze and evaluate these processes on the basis of their efficiency to reduce the sludge volume and energy requirement in the context of Nepal.

1.1 Country Context

Nepal is a mountainous landlocked country in South Asia which is bordered by China to the north and India to its east, west and south. It is located between latitudes 26^{o} 22'N to 30^{o}27'N and longitudes 80^{o}04'E to 88^{o}12'E. The land area of the country is 147,181 km^2 and it houses diverse topography, geology and climate which have created diverse culture and ways of livelihood within the country (Regmi, n.d). Geographically the country is divided into three regions, Himalayan, Hilly and Terai (Southern plains). Predominantly a mountainous country, 77% of its land falls under hills and mountains and the remaining 23% is occupied by Terai, the flat land (Shukla, Timilsina and Jha, n.d). The elevation of Nepal ranges from 64 m to 8848m above the sea level. Administratively, the country is divided into five development regions and 75 districts and 14 zones (Regmi, n.d and Shukla, Timilsina and Jha, n.d).

According to the census of 2011, the total population of Nepal was 26.62 million of which two third of the population are dependent on agriculture for their livelihood and the sector contributes 40% of the national GDP (Shukla, Timilsina and Jha, n.d.).

1.2 Wastewater Generation in Nepal

The production of wastewater in Nepal and associated problems are of major environmental concern. The degradation of water quality of the rivers and other surface water bodies and associated human health and livelihood consequences is a primary concern of wastewater management (Shukla, Timilsina and Jha, n.d). The problem is more pressing in urban Nepal than rural due to high population density. In Kathmandu and other major urban areas of the country, waste waster production is via domestic, commercial and industrial routes. Primarily, urban areas have been responsible for direct disposal of wastes along river course which has degraded the water quality of river and other water bodies (Green, Poh and Richards, 2003). The industries contributing to a significant quantity of effluents include brewery, distillery, cement, cigarette and tobacco. Of the total 4,500 industrial units of different sizes, 50.9% is located within the Kathmandu Valley. The combined wastewater production of the industrial estates in the capital was estimated to be 800 m^3/day (Shukla, Timilsina and Jha, n.d).

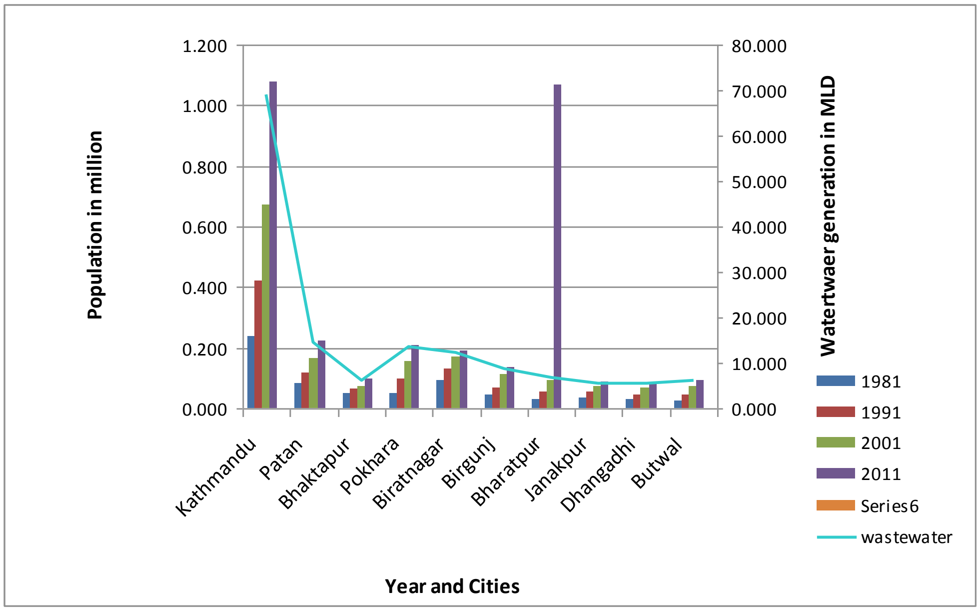

Figure 1: Population growth from 1981 to 2011 and waste water generation in major cities of Nepal

Source: Shukla, Timilsina and Jha, n.d.

1.3 Wastewater Treatment in Nepal

In Nepal, the concept of wastewater treatment is only two and half decades old. The country's few municipal wastewater treatment plants (WWTP) are concentrated in the Kathmandu Valley as shown in Table 1. It is evident from the table that almost all the large scale treatment plants established in Kathmandu are currently either nonfunctioning or partially functioning. The reason include high operation and maintenance cost along with the lack of the government and public interest in the issue (Green, Poh and Richards, 2003). In addition, due to the absence of a sludge management system in the country, most of the solid residue collected from the treatment plants is dumped into rivers without any treatment. Therefore, there is an urgent need to improve sludge management to prevent any public and environmental hazards resulting from improper sludge handling and disposal practices.

Table 1: Existing Wastewater Treatment facilities in Nepal

Location	Capacity MLD*	Current State	Service Details
Dhobighat, Patan (Ktm Valley)	15.4	Not working	HH Connections-53,900 Sewerage Lines-61,650 Combine channel- 44Km
Kodku (Ktm Valley)	1.1	Partially working	HH Connections- 15,500 Sewerage Lines- 20,443 Combine channel- 11Km
Sallaghari, Bhaktapur (Ktm Valley)	2.4	Not working	Details not available
Hanumanghat, Bhaktapur (Ktm Valley)	0.4	Nor working	
Guheswori, Kathmandu (Ktm Valley)	16.4	Partially working	Sewers- 6 Km Population Served- 53,000 Urban area- 21 Ha
Dhulikhel Hospital	<0.10	Working	Without Primary Treatment Bed Size- 261 m^2 Population served- 330
Kathmandu Municipality	<0.40	Working	No Primary Treatment Bed Size- 362 m^2 Population served- 330
Mulpi International School	<0.25	Working	No Primary Treatment Bed Size- 376 m^2 Population Served- 850
SKM Hospital	0.15	Working	Bed Size- 141 m^2 Population Served- 500
Kathmandu University	<0.035	Working	No Primary Treatment Bed Size- 587 m^2 Population Served- 1300
Pokhara Municipality	< 0.115	Working	No Primary Treatment Bed Size- 3,308 m^2 Population Served- 3830
Kapan Monastry (Kathmandu	< 0.015	Working	No Primary Treatment

Valley)			Bed Size- 150 m^2 Population Served- 300
Tansen Municipality	< 0.030		No Primary Treatment Bed Size- 583 m^2 Population Served- 1000
Sunga Community Wastewater Treatment Plant (Kathmandu Valley)	50 m^3/day	Working	Bed Size- 150 m^2 Population Served- 1200

MLD*= Million liters per day Source: Shukla, Timilsina and Jha, n.d

2 Sludge Characterization

Every year wastewater treatment plants usually generate millions of tons of residual solids as its by-product which is also referred to as sludge. On the basis of its origin, sludge can be categorized as sewage sludge, industrial sludge and sludge from drinking water treatment plants. In comparison to sewage and industrial wastewater treatment plants, drinking water purification generated significantly less amount of sludge (Lampert, Jessner and Kroiss, n.d. and Anderson, 2001). The characteristics of sludge are dependent on the pollution load of the treated water along with the mechanism of the treatment system. Generally, water treatment processes concentrated the pollutants present in the water; hence sludge contains a varied matter which includes organic matter, inorganic compounds, metals and also pathogenic pollutants (Harrison et a.l, 2003 and Anderson, 2001).

2.1 Types of Sludge

Sludge from a conventional treatment plants are derived from its primary, secondary and tertiary treatment processes. Individual processes adopted in waste water treatment have different impact on the pollutants.

2.1.1 Primary Sludge

The first phase of the wastewater treatment produces primary sludge. Primary treatment involves gravity sedimentation and flotation process that removes half of the suspended solids from the waste water (Stehouwer, 1999). Both organic and inorganic solid particles settle at the bottom after this stage (Stehouwer, 1999). Along with these physical mechanisms, chemical procedures such as coagulation and flocculation are also applied along to improve and accelerate the process of settling of suspended particles (UNIDO, 2011). Coagulation is the commonly applied chemical technique in wastewater treatment plants that removes waste particles from the water. Coagulants are a key component for this process which consolidates the suspended solids for easy and thorough removal. The coagulants are added in the waste water and destabilize the negatively charged particles, causing them to create clumps or flocs (Engelhardt, 2010). The process of coagulation is almost always combined with flocculation. Flocculants facilitate the agglomeration or aggregation of the coagulated particles to form larger floccules and thereby hasten gravitational settling. Some coagulants serve a dual purpose of both coagulation and flocculation in that they create large flocs that readily settle (Engelhardt, 2010).

Primarily, primary sludge mostly contains high portion of solid organic matter (Harrison et a1., 2003). It is a thick fluid with a water percentage of 93-97% gray on color and slimy have strong odor. After dewatering, its dry solid percentage increases to 30% (Harrison et a1., 2003). The specific gravity which is the total solid concentration in sludge ranges between 1.01-1.02. Generally, particle size of primary sludge is larger compared to secondary sludge since it contains more inorganic and fibrous components. The Total solid concentration varies depending upon the treatment processes. The overall sludge characteristic varies with solid concentration, particle shape and size (Harrison et a1., 2003).

2.1.2 Activated Sludge

Activated sludge, which is also known as secondary sludge, is the product of aerobic biological conversion of biological oxygen demand. Non degradable matters which primary treatment did not comprise are also included in this sludge. It is generated in secondary treatment which is controlled and accelerated by the introduction of biological components specifically naturally occurring microorganisms. These microbes decompose organic matter into simpler form, carbon dioxide and water (Pescod, 1992). The leftover matter which comprises flakes of microbial cell mass is the activated sludge (Hanjie, 2010). The composition of secondary sludge is given in Table 2.

Secondary sludge unlike primary sludge is gelatinous since it is generated from biological organisms. The amount of sludge produced during the biological process greatly varies with the treatment process, influent wastewater characteristics and temperature (Conveyance of Residuals from Water and Waste water treatment, 2000).

2.1.3 Mixed Sludge:

Primary and secondary sludge when put together is known as mixed sludge (Anderson, 2001). The proportion of sludge varies with plant and time. A typical plant would produce 50% primary and same percentage of secondary sludge on a weight basis. However, the characteristic of mixed sludge is not dependent on the proportion of sludge. Mixed sludge behaves more like activated sludge than primary sludge (Conveyance of Residuals from Water and Waste water treatment, 2000).

2.1.4 Tertiary Sludge

Tertiary sludge is produced by advanced waste water treatment processes which involved chemical precipitation and filtration. The composition of this type of sludge is determined by the chemical and the treatment process (Anderson, 2001 and UNIDO, 2011). Chemical sludge results from treatment processes that add chemicals, such as lime, organic polymers, and aluminum and iron salts, to wastewater. Generally, lime or polymers improve the thickening and dewatering characteristics of sludge, whereas iron aluminum salts usually reduce its dewatering and thickening capacity by producing very hydrous sludge (Anderson, 2001).

2.1.5 Digested Sludge

Digested sludge is produced after the anaerobic digestion of primary and secondary or activated sludge. It is reduced in mass, less odorous, contains less pathogen and is more easily dewatered than the first two types of the sludge (Anderson, 2001 and Hanjie, 2010).

Table 2: Composition of different types of sludge

Composition		Primary	Activated	Digested
Dry matter	g/L	12	7	30
Volatile matter	%	65	77	50
pH		6	7	7
N		4.5	6.3	6.2
P	%	2	2	2
Metals (Al, Fe, Mg)	%	2.8	2.8	2.8
C	%	51.5	53	49
H	%	7	6.7	7.7
Fats	%	18	10	10
Proteins	%	24	34	18

Source: Anderson, 2001

2.2 Composition of Sludge

The composition of the sewage sludge varies with the source of the sewage and the treatment procedures (Harrison et a1., 2003, Anderson, 2001 and Aktar and Sengupta, 2008). It contains both toxic and non-toxic organic matter. Non toxic matter is of plant and animal origin including protein, amino acid and fats. Whereas toxic components includes-polyaromatic hydrocarbons, pesticides, chloro-benzene, phenol and others. In addition to these organic waste materials, traces of metals like copper, zinc, cadmium, chromium and lead as indicated in Table 3 are also found in sewage sludge (Pescod, 1992 and Aktar and Sengupta, 2008). Sewage sludge also contains pathogenic microorganisms such as bacteria, viruses and protozoa which poses potential hazard to human health, animals and plants. Apart from the components which might have negative impacts on ecology, sewage sludge also contains significant amount of useful nutrients such as N, P and organic matter (Aktar and Sengupta, 2008).

Table 3: Concentration of Heavy Metals in Sludge

Metal	Dry Sludge, mg/kg
	Range
Arsenic	1.1-230
Cadmium	1-3410
Chromium	10-500
Cobalt	11.3-2490
Copper	84-17000
Iron	1000-154000
Lead	13-26000
Mercury	0.6-56
Tin	2.6-329
Zinc	101-49000

Source: Al-Malack, Abuzald, Bukhari and Essa, n.d.

2.3 Sludge Treatment

Rapid urbanization and industrialization have significantly increased the wastewater production which in result have produced high amount of sludge. Sludge contains varied quantities of pollutants such as heavy metals, dioxin, and other toxic chemicals (Pescod, 1992 and Aktar and Sengupta, 2008). It also contains pathogen and created nuisance with its bad odor (Aktar and Sengupta, 2008). . Hence, it stands as a threat to public health. Since sludge composition widely varies, it’s testing and regulation is problematic and often inadequate in developing countries. Hence, sludge treatment today is essential environmentally as well as socially and economically.

2.4 Sludge Treatment processes

Globally many treatment processes have been implemented for the treatment of sludge and it safe disposal later. Following are a brief description of sludge treatment processes.

2.4.1 Sludge Conditioning

Sludge conditioning further improves the processes of sludge thickening and dewatering. Conditioning does not reduce the water content of solids; it alters the physical properties of solids to facilitate the release of water during thickening and dewatering. There are two mechanisms involved in sludge conditioning- neutralization of charge and bridging of individual particles into the formation of solid flocs (Turovskiy and Mathai, 2006). Methods to condition sludge are explained below.

2.4.1.1 Chemical Conditioning

Chemical conditioning prepares sludge for better and economical treatment by thickening the sludge. Thickening is defined as increasing solid content of sludge by removing its liquid content. The advantage of increasing solid content of sludge includes reduction in total sludge volume (Garg, 2009). Chemical conditioning can be performed using compounds such as sulfuric acid, alum, ferrous sulfate and ferric chloride or mineral compounds such as salts or lime (Anderson, 2001). It leads to coagulation of the solids and releases the absorbed water. Through conditioning the moisture content of sludge is reduced from 90-99% to 65-85%. For the optimum chemical conditioning, intimate mixture of sludge and chemical is essential (Garg, 2009).

2.4.1.2 Thermal Conditioning

Thermal conditioning can be performed by two methods- wet air oxidation and heat treatment. In wet air oxidation, at temperature 450 to 550 oF and pressure of about 1200 psig sludge is oxidized without flame and reduced to ash. Similarly, heat treatment is conducted at 350 to 400 oF and pressure of 150 to 300 psig and the process improves the dewatering ability of the sludge (Garg, 2009 and Turovskiy and Mathai, 2006). Thermal treatment releases water that is bound inside the cell structure of sludge and hence improves the dewatering and thickening characteristics of the sludge. In this mechanism, sludge is grinded into smaller particles and is pressurized at about 300 psi. Next, compressed air is added and the mixture is brought to the temperature of 350oF by heat exchange between treated sludge and steam injection. The mixture is then processed in the reactor at required temperature and pressure (Garg, 2009 and Turovskiy and Mathai, 2006). The treated hot sludge is cooled with the incoming sludge and the gases are deodorized to reduce the smell. The sludge characteristics which influence chemical conditioning are sludge sources, solid concentration in the sludge, pH and other factors such as storage, pumping, and mixing and sludge treatment processes (Sludge conditioning, Turovskiy and Mathai, 2006).

2.4.2 Thickening

Thickening is a process that concentrates sludge to yield relatively moisture free condensed solid products. Along with reduction of water content, thickening also reduces the volume of biosolids, improves operation and reduces the cost for the subsequent storage, processing, transfer and end use or disposal (United States Environment

Protection Agency, 2003). This process reduces 10 to 30% of water content from the sludge. (Anderson, 2001). Various techniques of thickening are explained below.

2.4.2.1 Gravity Thickening

Gravity thickening is a commonly used technique and is based on the natural tendency of higher-density solids to settle (United States Environment Protection Agency, 2003). This process is primarily used for primary sludge thickening but can also be used for the combination of primary and secondary sludge. The compaction of primary sludge occurs faster and at higher concentration than secondary sludge (National Manual of Good Practice of Biosolids, 2005). A tank connected with a rotating pump and a collector at the base is required for gravity thickening. The sludge is fed into the system from the center well (National Manual of Good Practice of Biosolids, 2005). The solid settle at the base due to gravitational force and are extracted whereas, the wastewater is collected at the top. The process can thicken the sludge 2 to 8 times, significantly reducing the sludge volume. The benefits of this process include low operational cost and less energy requirement (United States Environment Protection Agency, 2003).

2.4.2.2 Gravity Belt Thickener

Gravity belt thickeners (GBT) is commonly used thickening method for activated sludge. It is comparatively easy to operate and require low energy along with manpower. In gravity belt thickening, as water passes though the porous horizontal belt solids are concentrated via gravity (National Manual of Good Practice of Biosolids, 2005). Gravity belt thickener consists of a long filter belt where thickening occurs in three phases-conditioning, gravity drainage and compression. Flocs of sludge are fed into the belt and as it moves, water passes through its weave. The sludge is further thickened by turning it over at the discharge end of the system. The belt is continuously washed by a high pressure wash station (National Manual of Good Practice of Biosolids,2005). Sludge thickening with a gravity belt thickener is made possible by the addition of polyelectrolyte to the sludge. Gravity belt thickeners are used for all types of sewage sludge (National Manual of Good Practice of Biosolids, 2005).

2.4.2.3 Dissolved air flotation

Thickening by dissolved air flotation (DAF) concentrates solids as a result of the attachment of microscopic air bubbles to suspended solids (National Manual of Good Practice of Biosolids, 2005). The process leads to the reduction of the specific gravity of the solids below than that of water. The attached particles float in the thickener tank and is removed via skimming. This technique is commonly used for activated sludge treatment because primary sludge could be settled in more economical process than DAF (Anderson, 2001). The solids to be fed into DAF thickener first mixed with pressurized recycle flow. The pressure is maintained at 75psig and the recycle flow rate varied with the feed rate (National Manual of Good Practice of Biosolids,2005.

The recycle flow is pumped to an air saturation tank where compressed air mixes and dissolves into the recycle. As the pressurized recycle containing dissolved air is reflowed into the DAF tank, the recycle releases the pressure that forms the air bubble for floatation (National Manual of Good Practice of Biosolids, 2005). The size of the bubbles formed ranges from 10 to 100 µm. Air and solid particles float and form a blanket on the surface of the DAF tank. The cleared effluent flows under the tank exit. 90% of the solid is concentrated by this method (National Manual of Good Practice of Biosolids, 2005).

2.4.2.4 Centrifugal thickening

Centrifuge thickener uses centrifugal force to separate solids. Centrifuge is widely used for the thickening of activated sludge in order to reduce transpiration cost (National Manual of Good Practice of Biosolids, 2005). Solid bowl conveyor is the commonly sued centrifuge technology as it has high efficiency. In general, the efficiency of a centrifuge is measured by thickened solid and solid capture. Factors that influence the efficiency of a centrifuge are sludge particle and flocs size, particle density, viscosity, consistency, temperature, presence of volatile solids, age of the sludge and its septicity (National Manual of Good Practice of Biosolids, 2005).

2.4.3 Dewatering

After thickening further dewatering of the sludge is conducted and it is achieved via mechanical process (Pollution Prevention and Control Technologies for Plating Operations, 2009). The physical removal of water from the sludge is essential economically as well as operationally. It makes the disposal and treatment process subsequently less cumbersome by increasing the solid content and reducing the volume (Vigneswaran and Kandasamy, nd). There are different types of dewatering processes which are discussed in the following sections.

2.4.3.1 Drying beds

Drying beds are mostly used for the dewatering of digested sludge. It comprise of perforated drainage pipe lined within a gravel base and is covered by sand (Sludge Handling and Disposal-Dewatering, n.d). The partitions surrounding the drying beds along with the ones between the drying beds are kept mostly open to atmospheric conditions. However, in wet climates it might be covered with ventilated structures that resembles green house (Sludge Handling and Disposal-Dewatering, n.d). Drying beds, in few hours separates the solid and liquid component of the sludge. In the bed, solid is raised on the top while the wastewater will remain at the bottom. The floating solid subsidies as the water are drained from the bed. The sludge is dried in the sand bed as water is drained from the sludge through the pipe. In addition, natural evaporations also influence the process of drying. Various designs, layouts of drainage pipe, thickness and type of material used in the gravel and sand layers and construction materials of partition are used for drying beds (Sludge Handling and Disposal-Dewatering, n.d and Pollution Prevention and Control Technologies for Plating Operations, 2009). There is no fixed time to remove the dried sludge from the bed. Factors such as availability of drying bed area, labor force and the moisture content of the sludge influences the removal time (Sludge Handling and Disposal-Dewatering, n.d). Besides, simple operation, low cost, and ability to function year through have made this method widely accepted. The disadvantages of this method includes land requirement, dependency on weather, odor and labor requirement (Anderson, 2001).

2.4.3.2 Centrifuging

Centrifuging separates water and solid components of solid through settlement and consolidation due to strong centrifugal force and sedimentation (Potrteous, nd). Typically, sludge is fed into a tube connected with a bowl and screw conveyor. The conveyor inside the conical bowl rotates at lower speed than of the bowl. So the sludge fed into the tube moves along the shaft of conveyor and is distributed at the periphery of the bowl. The solid which settle in the pool of waste water are compacted against the wall while the separated liquid is drained out continuously (Sludge Handling and Disposal-

Dewatering, n.d). This method is comparatively simple, compact, and flexible and also requires no chemical additions. Centrifuges are often installed by industries due to its low capital, simplicity in operation and effectiveness even with difficult to dewater sludge (Sludge Handling and Disposal-Dewatering, n.d).

2.4.3.3 Filter Press

Pressure Filtration is a process in which solid and liquid of the sludge is separated using filtering units. It does not produce dry sludge by applying pressure (Earnest Mine Complex Scarlift Report, n.d). In this method, sludge is fed into the feed holes of the press and applies pressure of 225 per square inch. The pressure causes the sludge to release water and pass via filter cloth while the solid residue remains in it. At the end of the chamber, the water released is collected. As the pressure is applied, the solid cakes produced are generally 10-20% drier (Earnest Mine Complex Scarlift Report, n.d). Dried sludge of maximum 75% solid can be produced using this technique. However, high operation and maintenance cost along with complicated batch operation are two major disadvantages (Sludge Handling and Disposal-Dewatering, n.d).

2.4.3.4 Filter Belt

In the filter belt process, the infeed sludge is mixed with plymer or other chemical and is put on the moving belt (Earnest Mine Complex Scarlift Report, n.d).The working principle is similar to that of gravity belt thickening. Dewatering of sludge occurs as the sludge is pressed in between two belts. The equipment used for this method is pressure dependent and the drying occurs up to 20% depending on the source of the sludge (Review of Sludge Dewatering Techniques, n.d and Anderson, 2001). Continuous operation, simple operation mechanism and moderate cost are the advantages whereas limited water reduction, energy and manpower requirement are the disadvantages of this process (Anderson, 2001).

2.4.4 Aerobic Digestion

Aerobic digestion is the oxidation of biodegradable and microbial mass of sludge by aerobic microorganisms (Moohkhum, 2007). In the process, organic matter is broken down into carbon dioxide and water along with new cellular material by the heterotrophic bacteria as indicated in equation 1. On decay of this newly formed cellular biomass more carbon dioxide, water and debris are formed which is shown in equation 2. Non-biodegradable components are not affected by this process. The finally produced digested product is a stable odorless matter which has dewatering characteristics (Banjade, 2008 and Moonkhum, 2007). Aerobic digestion can stabilize primary, secondary as well as digested sludge; however it is mostly suggested for activated sludge (Moohkhum, 2007). The process of aerobic digestion can be broken down into two steps:

Organic matter + O_2 + NH_4 $\rightarrow$ CO_2 + H_2O + Cellular material Eq 1

Cellular material + O_2 $\rightarrow$ CO_2 + H_2O + NO_3 + digested sludge Eq. 2

(Bacteria)

The rate of oxidation depends on the factors such as solid retention time, pH, temperature, mixing and the properties of raw sludge greatly affect the rate of aerobic digestion. Low capital, high reduction in pathogen is the benefits of this mechanism while high energy requirement for aeration is its limitation (Banjade, 2008).

2.4.5 Anaerobic Digestion

Anaerobic digestion degrades organic matter via microbes in the absence of oxygen (Banjade, 2008). It is a commonly practiced process in the treatment of primary sludge. This method is favored for its high efficiency in reducing high organic load. Compared to aerobic digestion, less cellular biomass is produced in this mechanism. Also, if sludge is treated anaerobically most influent is converted into end products thus leaving less residual biomass (Clisso, n.d.b).

Different microorganisms, mainly bacteria and methanogens are used for anaerobic digestion. The type of bacteria used depends upon the substrate that is mixed with the sludge is mixed and fed into the digester (Banjade, 2008). The conversion of complex organic matter into its simpler form is carried out into four stages:

a) Hydrolysis: Hydrolysis is a process in which large polymers such as proteins, are broken down by the enzyme produced by hydrolytic bacteria. The rate of hydrolysis depends on pH, temperature, organic matter and biomass nature (Clisso, n.d.b and Banjade, 2008).

b) Fermentation: Fermentation is also known as acidogenesis. In this stage, fermentative acigonesis bacteria convert sugar, amino acids and fatty acid to organic acids, alcohols and ketones. Along with these new products, hydrogen gas and carbon dioxide is also produced (Clisso, n.d.b and Banjade, 2008)

c) Acetogenesis: In this stage. Volatile acids and alcohols are broken down into acetate and hydrogen by hydrogen producing acetogenic bacteria. Hydrogen producing bacteria have symbiotic association with methanogens that uses hydrogen to produce methane (Banjade 2008 and Clisso, n.d.b).

d) Methanogenesis: It is the stage in which acetate, formaldehyde, hydrogen and carbon dioxide are converted to methane and water by methanogens (Clisso, n.d.b and Banjade, 2008).

2.4.6 Alkaline stabilization

Chemical stabilization of sewage sludge is also known as alkaline stabilization. It is a process in which chemical, primarily chlorine and lime, is added to the sludge (Farrell et. al, 1974). Addition of alkaline substances increases the pH of the sludge to 12 or higher. High pH halts the microbial metabolism. Hence, sludge will not putrefy or allow growth of any vector if pH is maintained high (Farrell et. al, 1974). The advantages of this process are easy conversion of other stabilization technique to alkaline stabilization. Addition of lime to sludge can be beneficial to agriculture. On the other hand, generation of greater quantity of end product creates difficltu in handling and the release of gases such as ammonia causes odor problem (Mahoney, 2006).

2.4.7 Composting

Composting is one of the preferred methods of sewage sludge neutralization. It is a complex process that destroys pathogenic organisms, stabilizes organic matter, dries sludge and produces end product that is environmentally useful (Kosobucki, Chmarzynski and Buszewski, 2000). During composition, aerobic bacteria decompose organic material and produce humus which is commonly called compost. This final product, compost, contains nutrients and organic carbon which improves soil quality. The optimum condition for composting are 50% moisture content, C:N ratio of 25-30:1 and temperature of 55^{o}C (United Nations Education Programme, n.d.).

Table 4: An overview of the of the various sludge treatment processes considering their sludge reduction efficiency and power consumption.

Treatment Mechanism	Efficiency (%)	Reduced Sludge volume (MLD)	Power kW/MLD
Gravity Thickening	8	0.012	0
Gravity Belt	10	0.015	3 - 6-
DAF	10	0.015	12-24-
Centrifuge thickening	22	0.032	16-41.6
Drying beds	60	0.088	N/A
Filter press	30	0.044	1100-2640
Filter belt	27	0.040	400-1200
Centrifuge dewatering	22	0.032	640-1600
Aerobic digestion	>90	0.133	24191
Anaerobic digestion	60-90	0.088 - 0.133	143
Composting	50	0.074	254.3

Sources: Akwo, 2008, Anderson, 2001, Borowitzka and Moheimani, 2012, Ghazy et al, 2011, Jonassen, Leonard, Crine and Stenstrom, 2008, National Manual of Good Practicefor Biosolids, 2005 and Huber Technology Wastewater Solutions, 2012.

3 Discussion

For the study, different treatment processes are studied and evaluated on the basis of their sludge compaction efficiency. The study also comprises the energy consumed by these processes for its operation. The summary is provided in Table 4.

Comparing the processes on its ability to reduce sludge volume, biological processes which are aerobic digestion, anaerobic digestion and composting has high ability to reduce sludge volume. According to Table 4, compared to biological processes physical processes are less efficient in the reduction of sludge volume. Amidst the physical techniques, drying beds comparatively condensed highest sludge volume. It was 60% efficient in compacting sludge. The least efficient process is gravity thickening which is a natural process and includes no additional equipment or energy source. Similarly, in terms of energy consumption, aerobic digestion is the most expensive mechanism. It requires 24191 kW electricity every day to decompose 0.133 million liters of sludge. Anaerobic digestion in contract to aerobic digestion has significantly less energy requirement. It consumed 143 kW of electricity for the same volume of sludge. The mechanical processes which are filter press, filter belt and centrifugal dewatering are also expensive in terms of their energy consumption. Their energy consumption ranged from 400 kW/MLD to 2640 kW/MLD. Gravity belt thickening and gravity thickening are the least energy expensive processes.

Of the two treatment processes examined on this paper, biological processes have higher volume reduction potential than the mechanical processes. Anaerobic digestion, aerobic digestion and composting, which are the biological processes, act upon the organic composition of the sludge. In these treatment mechanisms, aerobes and/or non aerobic microorganisms oxidize the degradable component of the sludge and significantly reduce the moisture content along with sludge volume (Kosobucki et a1., 2000). Energy requirement for aerobic process is the highest among all the available treatment processes as continuous aeration is required for the high volume sludge to create aerobic conditions. This condition is essential for the rapid consumption of organic matter by the bacteria. These aerobes convert organic content into carbon dioxide (Banjade, 2008 and Clisso, n.d.a). The organic matter reduces in sludge, bacteria dies and these dead cellular mass becomes the source of energy for other microbes present in the sludge thus this results in the reduction of sludge volume (Banjade, 2008). In contrast to aerobic digestion of sludge, anaerobic digestion has low energy consumption. The facultative and anaerobes break down the complex organic matter into simpler forms in different stages.

Table 5: Ability of different biological processes to reduce pathogen, odor and putrefaction control

Process	Pathogen removal	Reduce putrefaction	Odor control
Lime Stabilization	Good	Fair	Fair
Aerobic Digestion	Fair	Good	Good
Anaerobic Digestion	Fair	Good	Good
Composting	Fair	Good	Good

Source: Kocamemi, n,d.

These decomposers also release the bound water from the complex molecules thus obtaining water and food for their metabolic activities (Clisso, n.d.a). Methane, an odorless and inflammable gas is emitted at the end of this process along with the production of humus (Banjade, 2008 and Clisso, n.d.a). Similar to aerobic digestion, composting too utilizes aerobic bacteria for the oxidation of organic matter and reduction of sludge volume. The final product of the process is reduced in volume, odor as well as pathogen (Kosobucki, 2000). Compost is nutrient rich and performs best as soil conditioners. These nutrients and organic carbon rich environment friendly end product thus formed is of significant agricultural and economic value (United Nations Environment Programme, 2000). In addition, biological processes also assist in significant reduction of pathogen in the sludge (see Table5).

Compared to the biological processes of sludge treatment, the physical processes of thickening and dewatering reduce less sludge volume. Of the two mechanical processes, thickening had lower efficiency rate in sludge volume reduction. The objective of thickening is to lessen the volume of residual products and thus improve further operation of the treatment process (Environment Protection Agency, 2003 and Garg, 2009). Of the four thickening processes, gravity thickening was the least beneficial one as it was a system based on the natural phenomena and had no additional equipment associated. Centrifuge thickening has the highest ability to reduce sludge volume along with high energy consumption. Likewise, among the dewatering techniques drying bed was the most efficient one. It significantly reduced the sludge volume at low energy requirement. However, large land requirement, odor problem and public health hazard are the limitations of this process. The other dewatering processes which are centrifuge, filter press and filter bed are machine dependent process and thus have high energy requirement. However, their efficiency compared to power consumption was quite low.

The other processes of sludge treatment which are conditioning and lime stabilization are also evaluated however due to lack of data they were not included in the table. The conditioning is a pretreatment of sludge which prepares the sludge for further processing. Therefore, efficiency is expected to be low. However, energy consumption by thermal conditioning would be much higher than chemical conditioning (Anderson, 2001). Also, in chemical conditioning, the solid volume in the sludge would increase due to additional chemicals such as coagulants and flocculating agents. Lime stabilization also would increase the amount of solid in the sludge as it is also a chemical process like chemical conditioning. This chemical stabilization of sludge is very efficient in pathogen removal and inhibiting any microbial growth due to basic condition. Additional advantage of this process is that high pH limits the solubility and mobility of the metals present in the sludge. The free calcium ions supplied by the lime react with the other elements and form complex species. Also, it is an exothermic process which releases heat and the heat pasteurizes the sludge (Arthurson, 2008). Hence, it can be expected that some sludge volume will be reduced.

4 Recommendation

- **Scenario 1: Gravity Belt Thickening and Anaerobic Digestion**

  Thickening of sludge increases the solid content and thus reduces the cost of sludge handling and disposal (United States Environment Protection Agency, 2003) while anaerobic digestion significantly decomposes organic content thus resulting in significantly less volume of sludge (Banjade, 2008). Combining gravity thickening with anaerobic digestion would significantly reduce sludge volume in the context of Nepal. The thickening process via gravity thickening requires minimum energy. Other benefit of sludge thickening before anaerobic digestion includes maximization of digester capacity. Water content of the un-thickened sludge limits the ability of anaerobic digester. The well thickened feed also enables the optimum utilization of organic matter by the facultative and anaerobic bacteria. In terms of energy consumption, combination of these two processes requires 143 kW power per MLD sludge as gravity thickening has nil energy demand. The amount of heat required in the digester is also reduced as the excess water in the sludge is removed. Removal of excess water also assists in maintaining the alkaline buffer in the digester as the process of digestion is pH sensitive (Banjade, 2008). An additional benefit of anaerobic digestion is the production of methane gas. If this gas could be captured it can contribute to the energy demand of the plant for digestion as well as thickening.

Although the scenario is very much applicable in Nepal, there are limitations to its application. A major drawback of this process is the metal accumulation which is not treated during the process. Also, installing the operating unit with sufficient attention given on the safe handling of its emissions and end products require high capital cost.

- **Scenario 2: Gravity Belt Thickening and Composting**

Composting sludge after its pretreatment is a second scenario which could be adopted for the sludge treatment process in Nepal. Composting of biosolids is a biological thermal aerobic process that reduces organic matter significantly. As the name suggest, the process produces compost as an end product which is of high agricultural value. On the other hand, sludge thickening via gravity belt thickening reduces the moisture content of sludge up to 60% which is the ideal condition for composting (Anderson, 2001 and Banjade, 2008). Also, during composting heat is generated which evaporates the moisture content in the sludge. If the sludge is pretreated then the heat consumed for evaporation of water can actually act on the organic matter and reduces much amount of sludge. Addition of coagulating agents during gravity belt thickening will also increase the solid content of the sludge hence the amount of compost produced will also increase. Thus, if the process of thickening is combined with composting, the effectiveness will multiply.

However, the limitation of thus co-treatment is that the amount of water reduced by thickening via gravity belt thickener depends upon the characteristics of raw sludge. Secondary sludge is efficiently dewatered than primary sludge thus affecting the amount and efficiency of the co-treatment. Scenario 2 is slightly energy expensive compared to Scenario 1.

- **Scenario 3: Centrifuge Thickening and Anaerobic Digestion**

As mentioned in scenario 1 sludge thickening can significantly enhance the process of anaerobic digestion. The sludge with reduced water content increases the capacity of anaerobic digester and also minimized the amount of energy consumed by the digester. In this scenario, another method of thickening which is centrifugal thickening is suggested for its increased efficiency of sludge compaction. This method of thickening is two times more efficient than the thickening process suggested in scenario 1. The benefits of centrifugal thickening before anaerobically digesting sludge are similar to that of scenario 1. However, the difference between scenario 1 and 3 is in terms of energy consumption. This scenario has higher energy consumption as centrifugal thickening is comparatively energy expensive than gravity belt thickening. The total energy requirement ranges from 159 – 184.6 kW/MLD. This energy lost can be recovered as in scenario one. Once the energy is recycled within the boundary, the external energy source can be removed.

The limitation of this scenario however, is that it does not incorporate the capital and operational costs. Also, the metals and clogging might affect the efficiency of centrifugal thickening as well as in the digester.

- **Scenario 4: Centrifuge Thickening and Composting**

Similar to scenario 2, pretreatment of sludge is recommended before composting. The pretreatment process suggested in this case is centrifugal thickening. As Nepal is an agricultural country, composting is a most viable and beneficial. Thickening of sludge as mentioned in scenario 2 enhances the process of composting. Pretreatment via centrifuge condenses the solid content of the sludge, thus promoting the decomposition of organic matter and reduction of heat required in composting. Centrifuge thickens the solid significantly which eases the situation for aerobes to oxidize organic content.

Like in any other situation, co-treatment of sludge also in this scenario also has its limitations. This is energy expensive than other three scenarios. Also, the centrifugal efficiency is largely dependent on sludge volume and characteristics. Secondary sludge compacts easily and efficiently than primary due to the size of sludge particles.

- **Scenario 5: Lime Stabilization and Composting**

Co- treatment of sludge first by chemical treatment and then biological is another suggested mechanism. Addition of lime turns the sludge alkaline which leads to the high removal of pathogenic bacteria. Liming can also enhance dewatering ability of sludge. Jonassen et a1. in her study in 2008 indicated that adding lime to sewage sludge has significantly increased the drying rate and reduced the drying time. The influence of lime on sludge drying was consistent with sludge characteristics. Moreover, reduced drying time also indicates reduced energy consumption. Hence, the composting could be done at with 254.3 KW/ MLD or higher energy requirement.

A major drawback of this process is that the amount of lime required for stabilization is dependent on the sludge characteristics. Moreover, the compost produced will be alkaline in nature and hence will not be suitable for application in the entire field. Necessary study on the agricultural land and crops type where the sludge would be applied is essential.

5 Conclusion

Thus, the growing population that has lead to urbanization and industrialization has significant environmental hazards. The production of wastewater and sewage sludge is one of the many negative impacts of economic and industrial advancement in developed as well as developing nations. The problem is more pressing in developing countries like Nepal as the poor facility and lack of public awareness and the government interest has lead to considerable damage to water bodies especially rivers. Moreover, lack of financial support and technology has increased the intensity of the problem. Thus, the current study, which is a literature based paper, evaluates the possibility of introducing treatment options available in the world. On the basis of analysis, recommendations have been made. The study emphasizes the need of introducing sludge treatment in Nepal. In the context of Nepal, rather than using a single treatment mechanism, establishing a combination of two techniques seems to be very much beneficial in reducing sludge volume along with saving energy. Combining a biological treatment either composing or anaerobic with a physical process of dewatering has the highest efficiency of volume reduction. Moreover, additional benefits associated with these combinations also look advantageous for Nepal. The requirements of sludge treatment are very similar to that of sewage sludge treatment and can be incorporated with the current wastewater treatment plants. However, much research and detailed study has to be done to fully understand the phenomena of sludge production and its treatment possibility in Nepal.

REFERENCES

Aktar, Md. Wasim and Sengupta, Dwaipayan. Sewage Sludge Disposal- Land Application – Environmental Problems – An Overview. Department of Agricultural Chemicals, Bidhan Chandra Krishi Viswavidyalaya. 2008.

Al-Malack, Muhammad H., Abuzaid, Nabil S., Bukhari, Alaadin A. and Essa, Muhammad H. Characterization, Utilization, and Disposal of Municipal Sludge: The State of The Art. The Arabian Journal for Science and Engineering. 2002; 27.

American Society of Civil Engineers. Sludge Source, Composition and Characteristics. Conveyance of Residuals from Water and Waste water treatment. 2000: 33-43

AMRC learning house. Org. Section VI: Review of Sludge Dewatering Techniques. Earnest Mine Complex Scarlift Report. N.d.

Arthurson, Veronica. Proper Sanitization of Sewage Sludge: A Critical Issue for Sustainable Society. Applied and Environmental Microbiology. 2008; 74: 5267-75.

Banjade, Sarita. Anaerobic/Aerobic Digestion for Enhanced Solidsand Nitrogen Removal. Virginia Polytechnic Institute and State University. 2008.

Borowitzka, Michael A. and Moheimani, Navid R. Algae for Biofuels and Energy. Springer Technology & Engineering. 2012: 178-181

Clisso, Mike. Solids Handling and Disposal. Water/Wastewater Distance Learning Website. N.d.

Clisso, Mike. The Anaerobic Digestion Process. Water/Wastewater Distance Learning Website. N.d.

Engelhardt, Terry L. Coagulation, Flocculation and Clarification of Drinking Water. 2010.

European Environment Agency. Sewage Sludge- a future waste problem? Indicator Fact Sheet Signals. 2001.

Farrell, Joseph B., Smith, James E., Hathaway, Jr. Steven W. and Dean, Robert B. (1974). Lime Stabilization of Primary Sludges. Journal (Water Pollution Control Federation. 1974; 46:113-22.

Flaga, A. Sludge Drying. Cracow University of Technology. N.d.

Garg, Neeraj Kumar. Multicriteria Assessment of Alternative Sludge Disposal Methods. Department of Mechanical Engineering, University of Strathclyde Engineering. 2009.

Ghazy, M. R., Dockhorn. T. and Dichtl, N. Economic And Environmental Assessment of Sewage Sludge Treatment Processes Application in Egypt. International Water Technology Journal. 2011; 1: 102-19.

Green, Hillary, poh, Saik-Choon and Richards, Amanda. Wastewater Treatment in Kathmandu, Nepal. Massachusetts Institute of Technology. 2003.

Hanjie, Zhang. Sludge Treatment To Increase Biogas Production. Trita-LWR Degree Project 10-20. 2010.

Harrison, Elllen Z., Telega, Lee, McBride, Murray, Bossard, Shawn, Chase, Larry, Bouldin, David and Czymmek, Karl. Considerations for Dairy Farms Regarding Use of Sewage Sludge, Sludge Products and Septage. Cornell Waste Management Institute Department of Crop and Social Sciences. 2003.

Huber Technology Wastewater Solutions. Sludge Dewatering. 2012.

Jonassen, Ola, Leonard, Angelique, Crine, Michel and Stenstrom, Stig. (2008). Energy Efficient Drying and Dewatering Technologies. International Energy Agency Industrial Energy-related Technologies and Systems (IETS). 2008.

Kosobucki, P., Chmarzyński, A. and Buszewski, B. Sewage Sludge Composting. Polish Journal of Environmental Studies.2000; 9: 243-48.

Lampert, C., Zessner, M. and Kroiss, H. Sewage Sludge Composition- A Multifunctional Information. Vienna University of Technology. N.d; 1003-1008.

Mahoney, Stephen J. (2006). Sludge Treatment Processes. Michigan Depatment of Agriculture. 2006.

Moonkhum, Monruedee. (2007). Aerobic Digestion of Waste Activated Sludge With Ultrasonic Pretreatment. Asian Institute of Technology. 2007.

Mountain Empire Community College. Sludge Handling and Disposal- Dewatering. Water/Wastewater Distance Learning Website. N.d.

National Biosolid Parthnerships. National Manual of Good Practice of Biosolids. 2005.

National Metal Finishing Resource Center. Pollution Prevention and Control Technologies for Plating Operations. Section 6- Wastewater Treatment. 2009.

Pescod, M.B. Wastewater Treatment And Use In Agriculture. FAO Corporate Documents Repository. 1992.

Porteous, G. C. Dewatering Sewage Sludge by Centrifuge. Department if Environment: Directorate General Water Engineering Research and Development Group. N.d.

Puchajda B. and Oleszkiewicz, O. Impact of Sludge Thickening on Energy Recovery from Anaerobic Digestion. Water Science Technology. 2008; 57:394-401.

Regmi, Megha Raj. Feasible Low Cost Sustainable Options to Maintain River Quality: Case Study of Kathmandu Rivers. N.d.

Rulkens, Wim. Sewage Sludge as a Biomass Resource for the Production of Energy: Overview and Assessemnt of the Various Options. Energy and Fuels. 2008; 22: 9-15.

Shukla, Ashutosh, Timilsina, Uttam Raj and Jha, Binod Chandra. Wastewater Production, Treatment and Use in Nepal. UN Water Activity Information System. N.d.

Stehouwer, R. Land Application of Sewage Sludge in Pennsylvania: Biosolids Quality. Pennsylvania State University, College of Agricultural Sciences, Cooperative Extension. 1999.

Turovskiy I.S and Mathai P.K, Wastewater Sludge Processing. 2006. A John Wiley & Sons, Inc., Publication.

United Nations Education Programme. Environmentally Sound Technologies in Wastewater Treatment for the Implementation of The UNEP Global Programme Of Action (GPA) “Guidance on Municipal Wastewater.” N.d.

United Nations Environment Programme. Environmentally Sound Technologies in Wastewater Treatment for The Implementation of the UNEP Global Programme of Actions (GPA). United Nations Environment Programme Division of Technology, Industry and Economics. 2000.

United Nations Industrial Development Organization. Introduction to Treatment of Tannery Effluents. United Nations Industrial Development Organization. 2011.

Unites States Environment Protection Agency. Biosolids Technology Fact Sheet: Gravity Thickening. Office of Water EPA (832-F-03-022); 2003.

Vigneswaran, S. and Kandasamy, J. Sludge Treatment Technologies. N.d.