CHARACTERIZATION OF MUNICIPAL WASTEWATER SLUDGE USING OXYGEN UTILIZATION REACTOR TECHNIQUE

ASSOC. PROF. DR. AHMAD TARMIZI BIN ABDUL KARIM
NORZILA OTHMAN
RAFIDAH HAMDAN

(FRGS VOT 0394)
UNIVERSITI TUN HUSSEIN ONN MALAYSIA

CHAPTER 1

1.0 INTRODUCTION

Sludge generated during wastewater treatment had been traditionally regarded as a necessary nuisance byproduct. Sludge can be defined as an active biological solid residue resulting from the treatment of wastewater. There are three types of sludge, namely, sewage sludge from septic tank, sludge from municipal treatment works and industrial sludge (Nathan and Robert, 2003). All three constitute growing management problems in sewerage industries throughout the world.

Sludge production will continue to increase as new sewerage treatment facilities are built to cater for the increase in population especially in urban areas. The large volume produced had made it impossible for many countries to assure complete treatment of the sludge before discharging to the receiving environment (Abdul-Hamid & Muda, 1999; Mahmoud *et al.*, 2002). Indah Water Konsortium (IWK) reported that in 2005 the total amount of sewage sludge generated in Malaysia was estimated at 6.5 million cubic meters. Recent data in 2007 reported that the volume increased to 7 million cubic meters (IWK, 2007).

Land application is a favorable practice to dispose off sludge in Malaysia and is thought to be very effective and efficient method. Sludge may be applied to agriculture land, forest, disturbed land or dedicated disposal sites (Alvarez *et al.*, 2003; Walker *et al.*, 2003). In this case, wastewater sludge is being viewed as a valuable resource especially as soil conditioner and nutrients for non food crop.

However, large volume of sludge will create problem to sludge management industry especially to ensure safe disposal of sludge because it contains diverse range of pollutants such as pathogen, inorganic and organic compounds. These pollutants are toxic, mutagenic or carcinogenic and may threaten crop yields, long term soil quality, wild life health or eventually constitute health hazard to human (Oleszkiewicz & Mavinic, 2002; Jensen & Jepsen, 2005). Improper disposal and handling of sludge may pose serious impact to the environment especially on soil and water cycles (Lazzari *et al.*, 1999; Dhanagunan & Narendran, 2001; Abdullah & Baki, 2006).

1.1 Problem Statement

In many countries, sludge management represents 50% of the total wastewater treatment cost. Disposal techniques adopted fall into three categories: application on land, disposal in a landfill or thermal technology (Campbell, 2000; Bradley & Dhanagunan, 2004). The selection of disposal method mainly depends on cost effectiveness factor.

At the moment, most of the municipalities in Malaysia are adopting land application as the main method for final disposal of municipal sludge. Land has long been a repository for sludge, often with few constrains attached to the practice. In some cases, sludge was applied onto land at extremely high loading rates. Currently, no attempt was done to use sludge as crop fertilizer and only small portion of the sludge was used for non crop. All over Malaysia, only municipal sludge from Pantai WWTP is being used as fertilizer for landscaping plants. Whatever disposal choices adopted, sludge removal from treatment facilities need to be well managed and controlled in order to protect human health and the environment.

The problems of sludge handling and disposal are further complicated by the fact that different wastewater treatment facilities, used in Malaysia, will produce sludge of different characteristics (Bradley & Dhanagunan, 2004; Abdullah & Baki 2006). An investigation on the characteristic of pollutants should be done in order to gain better understanding on the nature of the sludge. Knowledge on sludge characteristics is necessary to determine and decide the best option before treating and disposing sludge (Hope, 1986; Mahmoud *et al.*, 2003).

Several studies had reported on characteristics of Malaysian sludge (Dhanagunan & Narendran, 2001; Bradley & Dhanagunan, 2004; Abdullah & Baki 2006). However, these studies only reported on bulk parameters and heavy metals in sludge. There is no information on organic contaminants such as polycyclic aromatic hydrocarbons (PAHs) reported in these studies. Thus, there is a need to study on the nature of local municipal sludge. Information on sludge characteristic is valuable in providing knowledge of limit value of sludge to be disposed off.

1.2 Objectives

The objectives of this research are:

1) to determine the characteristic of bulk parameters of wastewater sludge
2) to determine the characteristic of organic contaminant of wastewater sludge
3) to determine the characteristic of biomass in wastewater sludge.

1.3 Significance of the Study in Malaysia

Current practice of sludge disposal in Malaysia is on land. Lack of understanding and mismanagement of land application of sludge has resulted in more contaminated sites. Therefore, in depth study especially on sludge quality need to be performed. Study on sludge quality needs to incorporate sludge characteristics on bulk parameters, heavy metals and organic pollutants. Recent studies and published literatures showed that not much information was reported on organic contaminant in Malaysian sludge (Dhanagunan & Narendran, 2001; Bradley & Dhanagunan, 2004; Abdullah & Baki 2006). The finding from this research may eventually lead to the development or improvement of the existing database on sludge characteristics in Malaysia especially in term of organic contaminants.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Sludge Management in Malaysia

Before 1993, sewerage services in Malaysia were under the jurisdiction of 144 Local Authorities. It was reported that 80% of the public sewage treatment facilities did not meet the standard set by Department of Environment. Sixty five percent of the five million cubic meters of sludge produced in Malaysia was untreated and discharge into waterways causing serious pollution to rivers in Malaysia (Abdul-Hamid & Muda, 1999).

Realizing that sewerage system in Malaysia were in a deplorable condition, an Act was introduced in 1993 to deal with the management of sewerage services in order to avoid problems of sewage pollution of receiving waters. The Sewerage Service Acts (SSA, 1993) empowers the Federal Government to take control of sewerage services in Malaysia and Department of Sewerage Services was formed as the regulator of the sewerage industry thus relieving the Local Authorities of this responsibility (Abdul-Hamid & Muda, 1999).

Furthermore, SSA (1993) allows for privatization of sewerage services, and subsequently Indah Water Konsortium (IWK) was offered a 28 years (later extended to 40 years) concession to operate and maintain the national sewerage system. Sewerage services are regulated by Department of Sewerage Services which is set up under the Ministry of Energy, Water and communication. In 2001, The Federal Government through The Ministry of Finance acquired the entire private equity of Indah Water.

Upon being awarded the concession to undertake the management of the sewerage services in Malaysia, IWK outlined a three-stage strategy for sludge management, namely, immediate, short term and long term strategies as illustrated in Figure 2.1. The figure shows that six different methods of treatment have been identified in the three-stage strategy.

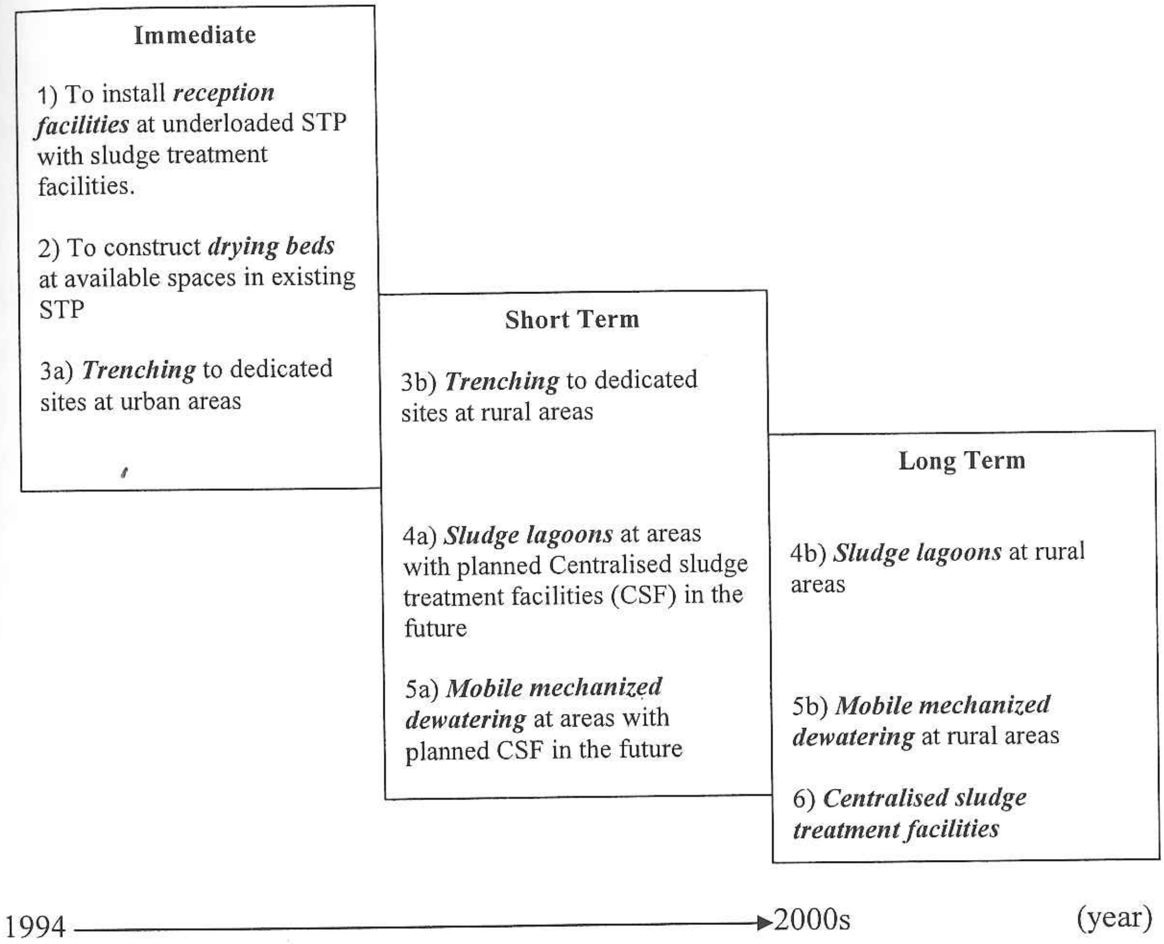


Figure 2.1: The Three-stage Strategy for Sludge Management formulated by IWK (Abdullah *et al.*, 2005a).

These methods include installation of reception facilities, drying beds, trenching, sludge lagoons, mobile mechanized dewatering and centralized sludge treatment facilities (CSF). Brief descriptions and relative merits of these methods will be discussed in the following sub-section (Section 2.4). It is interesting to note that trenching method is applicable under immediate and short terms strategy, while sludge lagoons and mobile mechanized dewatering methods are applicable under both short and long term strategy. This indicated flexibility in terms of location and economy. Suitable methods were selected based on ease of operation and maintenance.

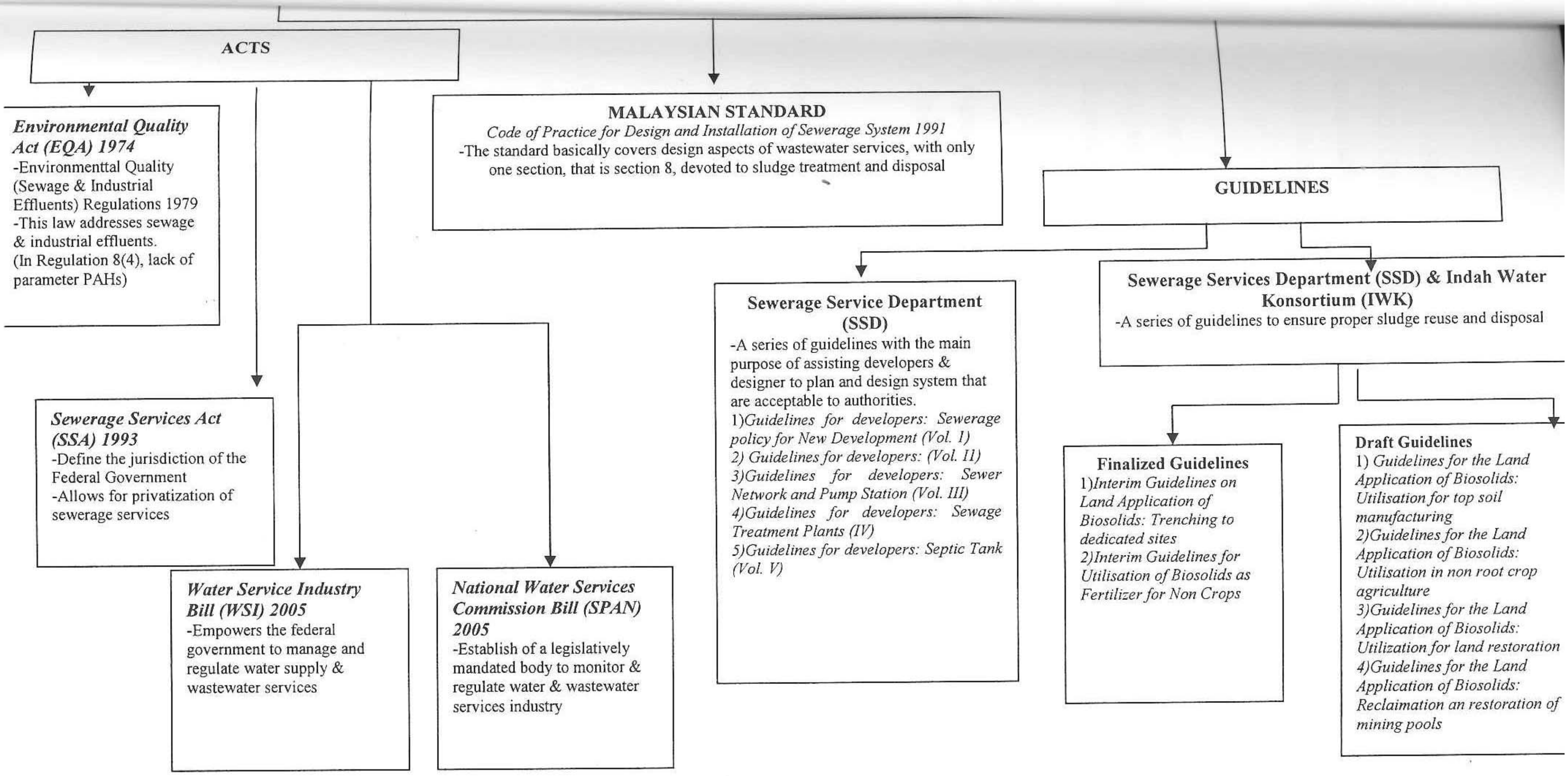
The methods provided in the three stage strategy are in compliance to Section 8 Malaysia Standard (MS 1228: 1991). According to the MS 1228: 1991, the sludge must be disposed of in a manner which does not give rise to nuisance or public health.

Apart from the SSA (1993) which was discussed earlier, the Environmental Quality Act (EQA, 1974) is another major piece of legislation that governs sewerage services activities, that addresses handling, treatment and disposal of sewage sludge in Malaysia. To support these Acts, the industry, with the assistance of relevant Government Agencies such as Standards and Industrial Research Institute of Malaysia (SIRIM) and Sewerage Services Department (SSD) have issued standards and guidelines to regulated sewerage services practices in Malaysia. Figure 2.2 illustrates the various Acts, Standard and Guidelines, that govern sewerage services in Malaysia (Othman *et al.*, 2007).

The EQA 1974 is a general law that specifies standard quality of effluents to be discharged. The EQA (Sewage and Industrial Effluents) Regulations 1979 was introduced to regulate sewage and industrial effluent.

Two new bills, namely, Water Services Industry Bill (WSI) and National Water Services Commission Bill (SPAN) were introduced in January 2005. The WSI Bill empowers the Federal Government to manage and regulate water and wastewater services in Malaysia, thus relieving State Government of these responsibilities. The SPAN Bill calls for the establishment of a legislatively mandated body to monitor and regulate water and wastewater services industry in Malaysia.

The Malaysian Standard (MS 1228) was introduced to regulate sewerage system design. This code of practice deals with the planning, design, construction, installation and testing of sewerage system, that include the sewers and sewer appurtenances, sewage pump stations, sewage treatment works and all other works necessary to collect, convey, treat, and finally dispose domestic sewage and industrial effluents. Procedures related to sludge treatment and disposal is covered in Section 8 of MS 1228. Treatment methods applicable in this standard include preliminary treatment, sludge thickening, mechanical dewatering facilities, anaerobic sludge digestion, aerobic sludge digestion, sludge drying beds and sludge disposal on land. The treatment methods proposed in the MS 1228 had been outlined in three stage strategies for sludge management formulated by IWK.



Environmental Quality Act (EQA) 1974
-Environmenttal Quality (Sewage & Industrial Effluents) Regulations 1979
-This law addresses sewage & industrial effluents.
(In Regulation 8(4), lack of parameter PAHs)

Sewerage Services Act (SSA) 1993
-Define the jurisdiction of the Federal Government
-Allows for privatization of sewerage services

Water Service Industry Bill (WSI) 2005
-Empowers the federal government to manage and regulate water supply & wastewater services

National Water Services Commission Bill (SPAN) 2005
-Establish of a legislatively mandated body to monitor & regulate water & wastewater services industry

MALAYSIAN STANDARD
Code of Practice for Design and Installation of Sewerage System 1991
-The standard basically covers design aspects of wastewater services, with only one section, that is section 8, devoted to sludge treatment and disposal

Sewerage Service Department (SSD)
-A series of guidelines with the main purpose of assisting developers & designer to plan and design system that are acceptable to authorities.
1)*Guidelines for developers: Sewerage policy for New Development (Vol. I)*
2) *Guidelines for developers: (Vol. II)*
3)*Guidelines for developers: Sewer Network and Pump Station (Vol. III)*
4)*Guidelines for developers: Sewage Treatment Plants (IV)*
5)*Guidelines for developers: Septic Tank (Vol. V)*

Sewerage Services Department (SSD) & Indah Water Konsortium (IWK)
-A series of guidelines to ensure proper sludge reuse and disposal

Finalized Guidelines
1)*Interim Guidelines on Land Application of Biosolids: Trenching to dedicated sites*
2)*Interim Guidelines for Utilisation of Biosolids as Fertilizer for Non Crops*

Draft Guidelines
1) *Guidelines for the Land Application of Biosolids: Utilisation for top soil manufacturing*
2)*Guidelines for the Land Application of Biosolids: Utilisation in non root crop agriculture*
3)*Guidelines for the Land Application of Biosolids: Utilization for land restoration*
4)*Guidelines for the Land Application of Biosolids: Reclaimation an restoration of mining pools*

Figure 2.2: Acts, Standard and Guidelines for Sludge Management in Malaysia

Five guidelines for developers were published by Sewerage Service Department (SSD). These guidelines provide clear policies in the development of new sewerage infrastructure. Sludge management is addressed in Guidelines for Developers: Sewage treatment plants (Volume IV).

In addition, six specific guidelines had been drafted by IWK and SSD to ensure proper sludge reuse and disposal. Two have been finalized while the remaining four are still under review (Abdullah *et al.,* 2005b). These guidelines focused on sludge reuse and disposal activities.

These Acts, Standard and Guidelines are used to regulate sludge management in Malaysia. Though these regulations are available, Malaysia still lacks regulations on the characteristics of sludge or parameter limits for disposal.

In considering the utilization of sludge in agriculture or any land application, a few factors must be addressed. Chemical quality limits must be set for the receiving soil to prevent loss or poor crop yield by virtue of uptake of chemicals. Toxic chemicals may accumulate in the food chain with serious consequences for human beings

A part from that, limit for microbiology factors must be set for especially for species of pathogen. Affordable treatment is needed to prevent the spread of such pathogenic organism to human, animal or plant. Aesthetic quality, which relate to odor and visual aspect of operation must also be accounted for. Finally, factors dealing with acceptability and accountability of the farmers must also be addressed. The usefulness of sludge and the requirement of a farmer will differ depending on area and crop types. Therefore the sludge must be applied in a manner that is satisfactory to farmers (Cecil *et al.*, 1998).

2.2 Advantages and Disadvantages of sludge for agriculture

Municipal sludge is a resource because it contains valuable nutrient to plants and improve holding capacity of poor soil. On the other hand, municipal sludge also contains toxic materials and harmful organisms for plants. The discussion below is directed to specific advantage and advantages of municipal sludge on agriculture.

2.2.1 Advantages of sludge for agriculture

Generally, there is an increasing interest in the agricultural application of sludge originating from municipal wastewater treatment plants, due to the possibility of recycling valuable components in the sludge. Sludge can provide nitrogen and phosphorus for plant growth. Several micronutrients such as zinc, copper and iron are also available in most sludge. The added organic matter enhance soil quality, making clay soils more permeable to water and air, and increasing the water and nutrient holding capacity of sandy or gravel soils. The texture of the soil can also be greatly improved (Edson *et al.,* 2007).

Previous studies had proven that the application of sludge to land offers several advantages (Bledsoe, 1981; Sopper *et al.*, 1982; Berglund *et al.*,1983, Cole *et al.*, 2001; Dolgen *et al.*, 2004). In recent years, there has been renewed interest in utilization of wastewater sludge, because of the drawback of other disposal methods (Hope, 1986; McBride, 2003).

According to Hope (1986), municipal sludge can be directly applied to croplands, forest, disturbed land as soil reclamation or as composted sludge for landscaping and gardening.

Studies on the beneficial uses of sludge from several places to date have established information on sludge use. Bledsoe (1981) studied the application of sludge in relation to timber production such as Douglas fir, polar and cottonwood. The study showed dramatic improvement in tree growth over unfertilized control areas. Study on the use of sludge for soil reclaiming at coal strip in Centralia, Washington, had proven that sludge was cost effective compared to other techniques such as adding topsoil, liming, fertilizing and irrigating (Sopper *et al.*, 1982). While Berglund *et al.*,(1983) reported that yield of some crops increased as much as three times compared to the use of commercial fertilizer on sandy or clay soils. In addition, composted or treated sludge is valuable for landscaping or gardening purposes. In Western Scotland, the application of sludge resulted in a better growth of *Isotomurus palustris* (Cole *et al.*, 2001). Dolgen *et al.*, (2004) had proved that sludge was a good soil conditioner to replace chemical fertilizer in growing lettuce. The above studies showed that utilization of sludge may represent a saving on disposal costs.

The application of sludge as fertilizer in agriculture lands represents an economic way to use the high amounts of sludge produced by the wastewater treatment plants. Currently, the agriculture sector is moving towards environmental friendly techniques with the goal of producing high quality crops. This requires the use fertilizer of high quality. Therefore limit value for heavy metals, organic micropollutants and pathogens must be established as a quality criterion.

2.2.2 Disadvantages of sludge

Though utilization of sludge is very promising especially for soils, there are several problems which must be carefully managed to protect the safety of the environment. The most serious of these are the harmful constituents of sludge such as heavy metals, toxic organics and pathogenic microorganisms. In some situation, there may be nuisance factors such as odor on the neighboring environment, which could give impact on land values. Public acceptance is also crucial to the success of any reuse of sludge. The public is reluctant to accept the reuse of sludge especially when associated with nuisance problem and disease vector. It is noted that data on microbiological quality are almost not existent in developing countries. Therefore, specific management practice and careful monitoring are required to mitigate these risks.

The contaminants constitute hazards for human health that may enter the food chain directly or through plant uptake. Studies from several researchers (as shown in Table 2.1) had proven that contaminants in sludge may cause significant effects towards health problem and life deterioration. Metals from the soils may also be absorbed onto root of plants. Many organic micropollutants are capable of uptake by plants. Another pathway for entry the food chain is through grazing animals. Infectious organism found in sludge can be neutralized by several treatments processes, such as, heating sludge or irradiation. However, these treatments are relatively expensive. Toxic organics on the other hand tend to concentrate in fatty tissues of animals. In the entire situation, human health can easily be put at risk, because high concentration of pollutants accumulated in plants and animals are consumed by humans.

Table 2.1: Effects of pollutants in sludge on human health

Pollutant	Researcher/Year	Specific elements	Effects
Heavy metals	Munger, 1983	Mercury, Arsenic	Acute & chronic poison of animals & human.
		Cadmium	Accumulate in kidney & cause irreversible kidney damage.
	Duraibe *et al.*, 2007	Zn	Vomiting, diarrhea, liver & kidney failure
		Lead	Disfunction of reproductive system
Organic contaminants	Mastrangella 1996	Phenanthrene	Photosensitizer of human skin & mild allergen
		Napthalene	Hemolytic anemia & nephrotoxicity
Pathogenic organisms	Bryan *et al.*, 1977	Bacteria (Salmonella spp)	Food poisoning & typhoid fever.
	Hurst, 1989	Virus (Rotavirus)	Digestive problem
	Martin *et al.*, 1990	*Ascaris lumbricoides*	Abdominal paint, vomiting

2.3 Impact of heavy metal in sludge

High concentrations of heavy metals in the environment are undesirable as they may have potentially adverse effects on the health of organisms. This problem will further poorer especially if they are included in the ecological cycle that can cause chronic illness due to metal accumulation in the bodies of living organisms. In the case of sludge, the problem of heavy metals is related to various purposes of sludge reuse.

Studies related to heavy metal compounds in municipal sludge had proved that the most common heavy metals discharges in natural environment are zinc, lead and cadmium.

Published literatures had proved that zinc is one of the most common heavy metals in wastewater sludge. High concentration of zinc in the sludge causes by consumables and toiletries in consumer products. At pH value below 7, zinc is present as divalent cation. It can readily form complex with organic and inorganic compounds. In wastewater, zinc is readily adsorbed onto suspended solid and become incorporated in sludge (Torn & Lavado, 2008). Even though zinc is an essential element or micronutrient, excessive amounts have been known to cause gastroenteritis upon ingestion.

Lead is a non-essential, highly toxic metal, and all known effects of lead on biological systems are deleterious. Sources of lead in the environment include atmospheric emissions, vehicular emissions, fossil fuel combustion, and industrial emissions. It exists in both inorganic (Pb(II) and Pb(IV)) and organic forms (up to four Pb-C bonds). Inorganic lead is known to be cycled globally more significantly than organically bound lead. Nevertheless, organically bound lead compounds may contribute significantly on a local scale. The occurrence of lead in drinking water is mostly the result of contamination of the water source or corrosion in the distribution system where lead piping is used (Clement *et al.*, 2000). Acute and classical lead poisoning in human adults is manifested by anemia and renal damage. Lead levels higher than 0.8 mg/l in the bloodstream have been considered to be the level for clinical lead poisoning even though symptoms are sometimes encountered with a blood lead concentration of 0.6 mg/l or less (Kwong *et al.*, 2004). The amount of lead released into water from wastewater treatment plants depends on the range and nature of effluents discharged. Approximately 80-100% of lead from industrial discharges, highway run-off in addition to domestic wastewater is incorporated into sewage sludge during treatment, and the remaining effluent discharged into waterways (Jian-Wang, 1997; Merrington *et al.*, 2003).

Cadmium is mainly used for electroplating, pigments, nickel-cadmium batteries or electronic equipments. Generally in Malaysia a separate sewer networks is adopted. The sewer network only caters for municipal wastewater while industrial wastewater is channeled for other means of treatment and storm water is conveyed in open drains. Based on the network system adopted, cadmium is supposed not to be detected in Malaysian municipal sludge. Hence, study on cadmium in municipal sludge is valuable in providing knowledge of non point sources of cadmium. Cadmium may be passed through the sewer network via open access in household plumbing or directly discharge into roadside manhole as illegal discharge.

Cadmium has been established as a very toxic heavy metal. Cadmium tends to accumulate in the kidney and liver of human body (Baker *et al.*, 2002). The human body seldom excretes as much cadmium as it absorbs. Cadmium interferes with the metallothionein's ability to regulate zinc and copper concentrations in the body. Metallothionein is a protein that binds excess essential metals to render them unavailable. When metallothionein activity is induced, the metallothionein binds to copper and zinc, thus disrupting the homeostasis levels (Noraberg *et al.*, 2009.). Cadmium toxicity to aquatic organisms is influenced by species, size, age, hardness, pH, complexation, and their diet. Cadmium is acutely toxic to fish in the order of 1.0 to 5080 ng/l and is markedly affected by water parameters such as hardness, and dissolved oxygen concentration.

The presence of potentially toxic heavy metals in the environment is very much a concern, primarily due to their non-biodegradability and persistence in the environment

(Alvarenga *et al.*, 2007). It has been a cause of considerable attention for sludge containing heavy metals due to the high desire for safety and clean sludge.

Some metals are also known to become concentrated in food chains through bioaccumulation, notably, mercury and cadmium (McAloon and Mason, 2003). Low concentrations of certain metals are harmless and traces are considered good for nutrition; for example, cobalt, copper, iron, selenium, and zinc are considered nutrients needed for balanced growth. Higher dosages may cause toxicity that is acute, chronic, or mutagenic/teratogenic (Claxton *et al.*, 2007). Hence, removal of heavy metal from sludge before disposal or reuse is a necessary step towards a sustainable sludge management and treatment.

2.4 Effect of Heavy Metals on Biological Systems

In most municipal wastewater treatment facilities, a biological system is employed to oxidize organics from the wastewater. In an activated sludge system, microorganisms utilize organic matter in the wastewater as substrates under aerobic conditions, thus removing them by microbial respiration and synthesis. These microorganisms include bacteria (both single and multicellular), protozoa, fungi, rotifers, and nematodes. The principal organisms involved in bio-oxidation of organic substances in wastewaters are the single celled bacteria. Protozoa does not use the organic substances in the wastewater but instead feed on the bacterial population. Rotifers, on the other hand, feed on activated sludge fragments that are too large for protozoa. Nematodes use organic materials that are not readily oxidized by other microorganisms (Verlecar *et al.*, 2006).

When the concentrations of soluble heavy metals in wastewater are increased, the activity of the microorganism will decrease. This will reduce the efficiency of a biological treatment system in degrading and may cause the effluent quality to deteriorate. If dissolved heavy metals are present in sufficient concentration in the influent to a biological treatment system, the metals tend to accumulate in the system's biological treatment operations, and this may decrease the operating efficiency in removing organic matter and suspended solids (Pérez-De-Mora *et al.*, 2006; Zhang *et al.*, 2008). This decrease in efficiency may also cause the metals concentration in the effluent to increase.

In conventional wastewater treatment, metal ions are removed through primary settling and in the activated sludge process. Primary settling removes a proportion of metals that are either insoluble or adsorbed onto the suspended solids (Northcott, *et al.*, 2007). In the activated sludge process, microorganisms biologically degrade materials (dissolved or suspended organic compounds) and convert them into carbon dioxide, water, and cellular materials (Wilén *et al.*, 2008). The microorganisms form aggregates or flocs and then pass into a settling tank (sedimentation). Hence, any substance or metal that is adsorbed by the bacterial flocs may be partially removed from the water through a combination of microbial adsorption and sedimentation processes.

Factors which affect the settling properties of mix liquor such as loading rate, feed composition, mixing strength, and sludge volume index will also affect its capacity to remove metals (Jin *et al.*, 2003). Over a certain range of metal loadings (<2 mg/l), there seems to be a linear relationship between the initial heavy metal loading and percentage of heavy metal removal for cadmium and chromium (Jin *et al.*, 2003). The concentration of metals in the solids produced may be as much as twenty to thirty times greater than the concentration in the influent due to accumulation of metals in the sludge (Eysenbach *et al.*, 1992; Chipasa, 2003).

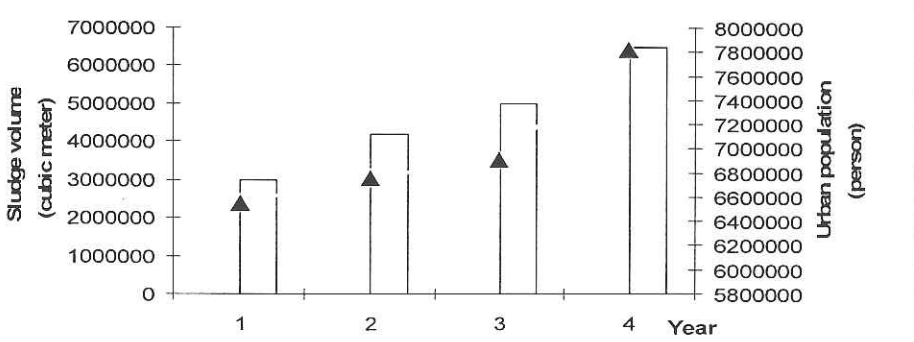
2.5 Problem Associated with Sludge Management

In an attempt to improve the sewerage services in Malaysia, the government through IWK had built more centralized and permanent treatment facilities. Generally, the higher number of treatment facilities leads to the increase in the amount of sludge generated annually. The large amount of sludge is the main challenge for sewerage industry especially to assure safe treatment and disposal.

2.2.1 Sludge Quantity and Associated Problems

The quantity of sludge produced annually in Malaysia has increased dramatically since the introduction of central sewerage system in 1990. Active research was done by Indah Water Konsortium (IWK) to establish the amount of sludge produced in all sewerage treatment facilities under its responsibilities. In 1999, Mohd Din & Velayutham had reported about 3 million cubic meters of sludge had been produced. Following that in 2000, it was reported that 4.2 million cubic meters was produced (Bradley & Dhanagunan, 2004). In 2001, it was reported that the amount had risen to 5 million cubic meters (Dhanagunan & Narendran, 2001). Until 2005, the reported value of sewage sludge generated in Malaysia was estimated at 6.5 million cubic meters. Based on the observed data over six years, the increase in sludge production rate is 0.58 million cubic meters over six years.

In Malaysia, sludge production will continue to increase as new sewerage treatment facilities are constructed to cater for the increase in population especially in urban areas. Figure 2.3 illustrates that the volume of sludge increased as the urban population increased. The correlation factor between sludge volume and urban population in Malaysia is 0.95. This shows that the sludge volume highly depends on urban population (Othman *et al.*, 2007).



Urban population and sludge volume in 1999, 2000, 2001 and 2005
(sludge volume: Mohd-Din and Velayutham, 1999; Dhanagunan and Narendran, 2001; Bradley and Dhanagunan, 2004; IWK, 2005 ; Population data: Dept of Statistic).

Figure 2.3: The Volume of Sludge and urban population at different years

The large volume produced had made it difficult for many countries including Malaysia to assure complete treatment of the sludge before discharging to the receiving environment (Abdul-Hamid & Muda, 1999; Mahmoud *et al.*, 2002).

2.5.2 Sludge quality and Problems

In general, advance wastewater treatment can increase the total volume of sludge generated. A part from that, advance treatment also increases the concentration of contaminants in sludge, because many of the constituents removed from the wastewater end up in sludge. Furthermore, wastewater treatment processes that involve the addition of chemicals such as coagulant to precipitate solid will result in increase of these chemicals in the sludge. Indirect effects include adsorption of phosphorus by alum or causes trace metals (e.g. cadmium) to precipitate out of the wastewater into sludge (Hope, 1986). Thus, the type of treatment or pretreatment adopted affects the characteristic of sludge.

Different wastewater treatment processes which include individual septic tanks, communal septic tanks, oxidation ponds, aerated lagoons and mechanized sewage treatment plants generate various sludge characteristics. These are among challenges faced by sewerage services provider in selecting suitable sludge treatment methods. A good practice in sludge management should focus in minimize the risk associated with the sludge. Proper precautions measures depending on sludge quality, disposal site characteristic and intended uses are needed before deciding on sludge reuse.

At present no local limit for quality of sludge to be disposed off. A part from that lack of guidelines and local standards for surface and ground water contamination cause by sludge disposal activities among challenges face by IWK in monitoring 28 disposal activities including trenching sites, drying beds and sludge lagoons (IWK, 2007).

The government through its regulating agencies needs to set up regulations as well as pollution prevention methods that can reduce the level of heavy metals and other pollutants such as PAHs in the treated wastewater at wastewater treatment facilities and in the subsequent sludge produced.

2.6 Sludge Characteristics

Sludge characteristic depends on several factors. Factors such as origin of the sludge such as residential, commercial or industrial development, wastewater treatments processes involved in generating the sludge and incoming sewage characteristic will vary the content of sludge (Perez *et al.*, 2001; Mahmoud *et al.*, 2003; Abdullah & Baki, 2006).

Generally sludge contains about 93% to 99% water with the remaining percentage are solid and dissolve substances (Abdullah & Baki, 2006). In the past, characterization of sludge normally focuses on bulk parameters. The increase in environmental concern on sludge re-use had triggered a more comprehensive characterization of sludge which included bulk parameters, pathogens and micropollutants. The typical compositions of the above parameters generally consist of organic content, nutrient, pathogens, heavy metals and organic micropollutants. Fat, greases and food residue are among organic substances in sludge. Nutrients content in sludge included nitrogen, phosphorus, potassium, calcium and magnesium. Pathogenic organisms in sludge comprise bacteria, virus or worms that cause disease to human. The heavy metals of concern include lead, zinc, lead, cadmium, chromium and nickel. There are many organic micropollutants produced by modern technology from household detergent to pesticide that can appear in wastewater and finally in the sludge. Comprehensive sludge characteristics provide important information in order to identify suitable technologies in treating and disposing sludge (Mahmoud *et al.*, 2003).

2.6.1 Studies on sludge characteristics in Malaysia

Most studies on sludge characteristic have been carried out in temperate countries. Information on sludge characteristic in Malaysia is still limited. Nevertheless, in recent years, few studies on characteristics of Malaysian sludge had been reported. Several groups of researchers had reported on sludge from different states in Malaysia (Dhanagunan & Narendran, 2001; Abdullah & Baki, 2006). In addition to this, Bradley & Dhanagunan (2004) reported on sludge characterization from different treatment facilities. Figure 2.4 shows studies on sludge characteristic in Malaysia by different research groups.

It is clear that there is no agreement in the reporting of nutrients, organic and inorganic. Inconsistencies in reporting sludge quality parameters are attributed to the different objective of these studies. It is also apparent that no information on organic micropollutants such as polycyclic aromatic hydrocarbons (PAHs) was reported in these studies.

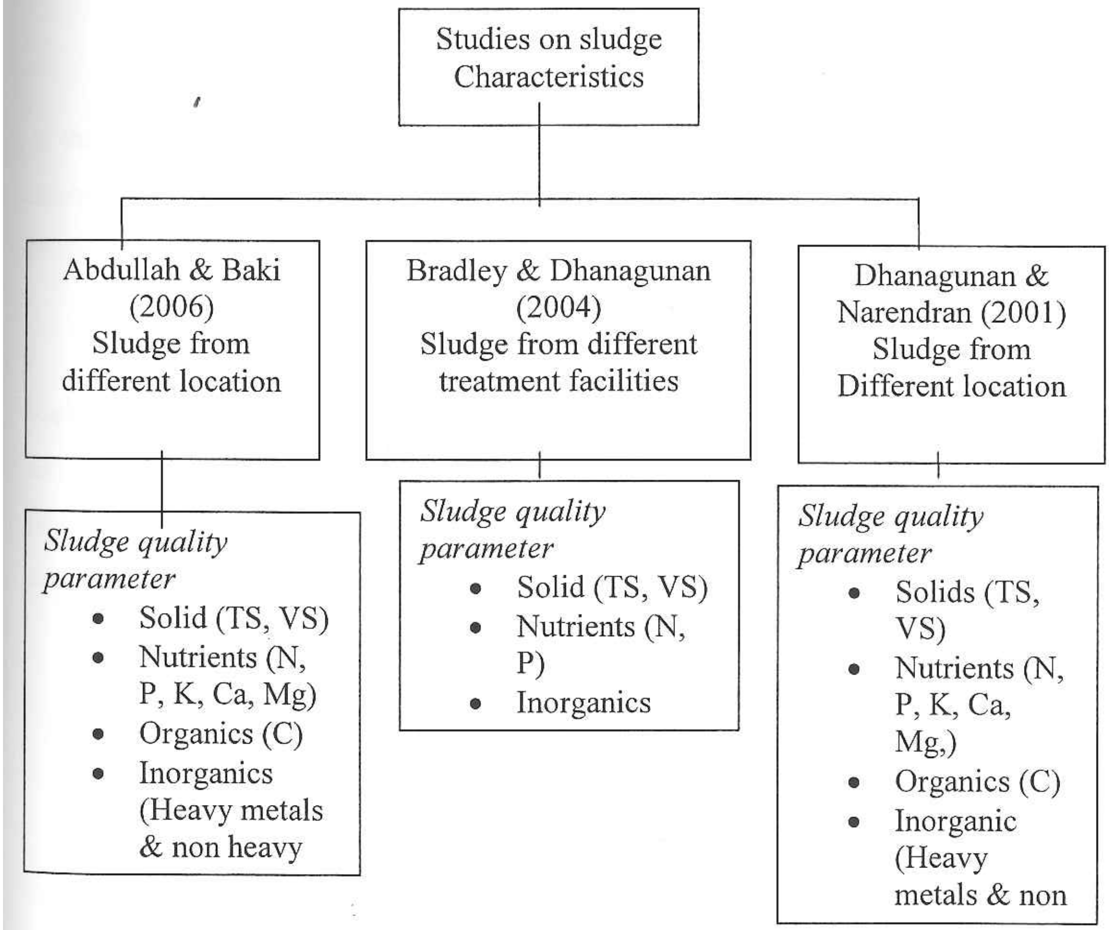


Figure 2.4: Characteristic of sludge in Malaysia

Complete sludge characteristics will provide knowledge especially on organic or inorganic compounds present in the sewage. Some researchers recommend that organic contaminants such as PAHs should also be considered in characterization of sludge (Lazzari *et al.*, 1998). However the characteristic and long term observation of organic contaminants in sludge has received little attention in many countries including Malaysia. Therefore no parameter limit values have been legally introduced for such pollutants.

Though available studies on sludge quantity and quality have made significant contribution in Malaysia, knowledge needed for planning, management and treatment of sludge is still vague.

2.7 Chemical characteristics of municipal sludge

Sludge management options require extensive sludge characterization since many of them may contain compounds deleterious for the ecosystem such as heavy metals. The chemical compositions of sludge from different countries show that sludge contain hazardous components that pose significant impact towards environment.

Table 2.2 shows that chemical constituents of municipal sludge were highly variable among plants, places and countries as indicates by the high standard deviation.. In addition to the inherent variability associated to these materials, intermittent discharges from several sources into each treatment plants also affect the constituents of contaminants in the sludge.

Table 2.2: Chemical characteristic of municipal sludge from different countries

Plants	COD (mg/l)	TSS (mg/l)	Zn (mg/kg)	Pb (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Ni (mg/kg)
Middlesex (USA)	40770 (10693)	33496 (2901)	351.9 (98.6)	64.2 (37.9)	2.5 (1.2)	5.6 (1.3)	1.9 (0.4)
Passaic Valley (USA)	86507 (20037)	79965 (32433)	136.7 (75.1)	317.8 (247.4)	7.3 (5.0)	140.2 (69.3)	12.6 (3.3)
Greece	34000 (1000)	25800 (760)	1034 (52)	83 (15)	4.4 (0.6)	104 (80)	165 (49)
Malaysia	40000 (5000)	10000 (900)	2500 (140)	150 (12)	3.0 (0.9)	5.0 (1.0)	35 (9)

Note: numbers in brackets indicate standard deviation
Sources: Edward & Thomas, 1987 ; Ujang & Othman, 1999; Mantis *et al.*, 2004;

Municipal sludge pollutants are, in general bound onto organic matter which is able to complex with or adsorb them. The final toxicity and bioavailability of these compounds depends on types and concentration of pollutants present in the sludge. It is, however, possible to recognize some general chemical and physical properties for heavy metals and organic micropollutants which influence their behavior in biodegradation of sludge.

Heavy metals in municipal sludge derived from the wastewater which generally contains high concentration of these elements. Heavy metals can be found in municipal sludge in different chemicals forms, namely, as salts, bound onto organic matter and in an adsorbed or exchangeable form. Moreover, the typical chemical forms are in general partitioned between the soluble and insoluble species in relation both to the state of the metal in the starting material or the nature and chemistry of the biodegradation process. Previous studies on metal specification have suggested that each heavy metal shows specific chemical characteristics during degradation process (Lazzari *et al.*, 2000).

Copper, lead and cadmium are characterized by their association with organic matter. However, large quantity of cadmium is exchangeable and available for leaching, but on the other hand lead and copper are not water soluble and less mobile. Cadmium mobility is attributable to the fact that Ca^{2+} adsorb rather weakly onto organic matter unless the pH is higher than 6, and subsequently increases markedly with pH up to around 8. Lead is the least mobile heavy metal, especially under alkali condition. As expected from the strong complexation of Pb^{2+} by organic matter, Pb bioaccumulates in the organic rich in sludge. Nickel is recognized as relatively mobile and water soluble and it leach under high pH. Zinc is soluble under alkaline condition (Henry and Harrison, 1997; Lazzari *et al.*, 2000). The above studies show that each heavy metal in municipal sludge has their own specific chemical characteristics. These chemical characteristics give significant impact to the biodegradation process.

2.8 Oxygen Utilization Rate (OUR)

Oxygen Utilization Rate (OUR) measurement was originally conducted by Ekama & Marais (1977). Back then, it was only applied to characterized wastewater. The method was then developed further by Sollfrank & Gujer (1991) and also Kappelar & Gujer (1992). Many researchers used this method to determined COD-fractions and bio-kinetic parameters (Ekama *et al.*, 1986 ; Henze 1986 ; Henze *et al.*, 1987 ; Sollfrank & Gujer, 1991 ; Kappelar & Gujer, 1992 ; Cokgor *et al.*, 1998 ; Naidoo *et al.*, 1998 ; Wentzel *et al.*, 1999 ; Vollertsen & Hvitved-Jacobsen, 1999 ; Abdul-Talib *et al.*, 2000). The OUR method enables the COD-fractions presents in wastewater and sludge to be evaluated. The COD-fractions are expressed in heterotrophic biomass, X_B, readily biodegradable substrate, S_S, fast hydrolysable substrate, $X_{S,fast}$, and slow hydrolysable substrate, $X_{S,slow}$.