Department of Mechanical Engineering

Multicriteria Assessment of Alternative Sludge Disposal Methods

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Signed: Neeraj Kumar Garg
Date: 09/01/2010

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Abstract

Sludge production from wastewater treatment process is high, and the disposal of excess sludge will be forbidden in a near future, thus increased attention has been turned to look into potential technology for sludge reduction. The study attempts to review alternative sludge disposal methods, including anaerobic digestion, aerobic digestion and landfills. In these sludge processes, excess sludge production can be reduced up to 100% without significant effect on process efficiency and stability.

Current waste water sludge production in U.K amounts to around 1.2 megatonnes of dry solids each year and for EU as a whole there are about 6.5 megatonnes of dry solids produced annually. The sludge production values has significantly increased, possibly by as much as 50%, as the urban waste water treatment directive was implemented over the period up to 2005 and in the next decade, sludge disposal to all the established outlets could become increasingly difficult. The challenges faced by the government are how to (a) maintain cost-effective and secure methods of sludge disposal and (b) engender public confidence in all disposal and recycling options.

This study would be useful when one is looking for appropriate environmentally and economically acceptable solutions for reducing or minimizing excess sludge production from wastewater treatment process. Here is the comparison of Sludge disposal methods i.e Anaerobic, Aerobic and Landfills, and carry out the research to find out the cost effective, calorific value and more environment friendly methods like labour cost, capital cost, Operating Cost, Process Time, Space requirement, Odours, Energy Balance, Biogas Production, Sludge production, Energy Cost, Reactor Volume, Application, BOD Reduction and Reliability. Studying the anaerobic, aerobic and landfill methods of sludge disposal and taking into account the survey and case study of Scottish Water's waste water treatment site Cumnock WWTW to conclude the best suitable method for sludge disposal.

TABLE OF CONTENTS

List of Figures

List of Tables

1. INTRODUCTION

In today's era, a strategic approach towards global impact on the environment must be developed and if this aspect is elapsed, a change of environmental loads or their effect will be caused and no reduction will be attained. For instance, a wastewater treatment plant (WWIP), which is a main concern for ecological treatment system, gives rise to an environmental impact due to its energy consumption, use of chemical compounds, emissions to the atmosphere and sludge production.

Sludge is the largest by-product from waste water treatment plants and its disposal is one of the most challenging environmental problems in waste water treating processes. Sludge is a by-product of water and wastewater treatment operations. Sludge from biological treatment operations is sometimes referred to as wastewater biosolids. Before sludge can be disposed, it needs to be treated to a certain degree. The type of treatment needed depends on the disposal method proposed. There are principally three final disposal strategies for wastewater sludge and sludge components even though there are many "grey zones" between these are clear-cut alternatives. Sludge and sludge components may be deposited on land (in landfills or special sludge deposits), in the sea (ocean disposal) or to a certain extent in the air (mainly as a consequence of incineration) [32].

The solids in the sludge contain nutrients of value to plants, as well as humus-like material which improves the capacity of poor soils to hold water and air. Unfortunately, industrial sources, including household wastes and urban runoff, introduce quantities of toxic materials into municipal sludge. Human waste also contains harmful organisms.disease-causing bacteria, viruses and parasites.

Sewage sludge consists of the organic and inorganic solids that were present in the raw waste and were removed in the primary clarifier, in addition to organic solids generated in the secondary/biological treatment and removed in the secondary clarifier or in a separate thickening process. The generated sludge usually is in the form of a liquid or semisolid, containing 0.25 to 12 percent solids by weight, depending upon the treatment operations and processes used. The problems of dealing with sludge are complex because:-

1) It is composed largely of the substances responsible for the offensive character of untreated waste water.
2) The portion of sludge produced from biological treatment requiring disposal is composed of the organic matter contained in the waste water but in another form, and it too, will decompose and become offensive.
3) Only a small part of the sludge is solid matter.

Current and future production of sludge in the UK is estimated, and it is predicted that recycling to agricultural land, and incineration (with energy recovery) will be the major disposal options for sludge in the future. The waste water sludge production in U.K amounts to around 1.2 megatonnes of dry solids each year and for EU as a whole there are about 6.5 megatonnes of dry solids produced annually. The sludge production values has significantly increased, possibly by as much as 50%, as the urban waste water treatment directive is implemented over the end of 2005. Environmental pressures on sludge recycling may lead to restrictions on application. Attention to sludge quality and the development of quality management practices in utilization or disposal operations will help to minimize environmental concerns and facilitate sludge disposal to all outlets [26].

Due to the forthcoming European Union ban on sewage sludge disposal at sea and associated environmental legislation which has increased the amount of sewage sludge produced annually in the UK, there is a need for consolidation and expansion of existing sludge disposal outlets and assessment of the suitability of alternative and innovative disposal options. This study reviews the main elements of sludge disposal methods in the UK in relation to their environmental sensitivity, sustainability and general security. Much of the additional sludge produced by changes in waste water treatment is likely to be accommodated by an increase in disposal by incineration and application to agricultural land [33].

1.1 OBJECTIVE:

The present study has been designed with the following objectives:

- To review the three technologies of sludge disposal methods i.e. Anaerobic Digestion, Aerobic Digestion and Landfills, and to enable which technology is most suitable for the type of conditions present.
- To show a comparison for the above three sludge disposal methods in terms of calorific value, cost effectiveness, risk factors and reliability etc.

2. Literature Review:-

This section of the report will explain elaborately the project background by elucidating the terms sludge disposal methods then discussing the different process. This section will also throw some light on the work done in the related fields with the help of case study, enabling to show the reason behind the study. Some processes are explained to understand the background of the study and ultimately ending up with the requirement of this study.

2.1 DIFFERENT PROCESS OF SLUDGE TREATMENT

Sludge is treated by various processes that can be used in various combinations. Following are the different types of sludge treatment processes with little detail.

2.1.1 SLUDGE DEGRITTING

In some plants where separate grit-removal facilities are not used ahead of primary sedimentation tank, or where the grit-removal facilities are not sufficient to handle peak flows and peak grit loads, it may be essential to remove the grit before further processing of the sludge. Where further thickening of the primary sludge is desired, a practical consideration is Sludge Degritting. The most effective method of Degritting sludge is through the application of centrifugal forces in a flowing system to achieve separation of the grit particles from the organic sludge. Such separation is achieved through the use of cyclone degritters, which has no moving parts. The sludge is applied tangential to a cylindrical feed section, thus imparting a centrifugal force. The heavier particles move to the outside of the cylinder section and are discharged through a cylindrical feed section. The organic sludge is discharged through a separate outlet. The efficiency of the cyclone degritters is affected by pressure and by the concentration of the organics in the sludge. To obtain effective grit separation, the sludge may be relatively dilute 1 to 2 percent. As the sludge concentration increases, the particle size that can be removed decreases [31].

Sludge from Treatment Processes

⇩

Preliminary Operations

Sludge Grinding	**Sludge Storage**
Sludge Bending	**Sludge Degritting**

⇩

Thickening

Rotary Drum Thickening	**Centrifugation**
Gravity Thickening	**Gravity Belt Thickening**
Floatation Thickening	

⇩

Stabilization

Chlorine Oxidation	**Anaerobic Digestion**
Lime stabilization	**Aerobic Digestion**
Heat Treatment	**Composting**

⇩

Conditioning

Elutriation	**Chemical Conditioning**
Heat Treatment	

⇩

Disinfection

Pasteurization	**Long Term Storage**

⇩

Dewatering

Vacuum Filter	**Centrifuge**
Pressure Filter	**Drying Bed**
Horizontal belt filter	**Lagoon**

⇩

Drying

Multiple Effect Evaporator	**Rotary Drying**
Flash Drying	**Multiple Hearth Drying**
Spray Drying	

⇩

Thermal Reduction

Multiple Hearth Incineration	**Flash Combustion**
Fluidized Bed Incineration	**Co-incineration with**
Vertical Deep Well Reactor	**Solid Wastes**

⇩

Ultimate Disposal

Landfill	**Reclamation**
Land Application	**Reuse**

Table 1: Different Process of Sludge Treatment.

2.1.1.1 Blending:

Sludge is generated in primary, secondary and advanced wastewater-treatment process. Primary sludge consists of settleable solids carried in the raw wastewater. Secondary sludge consists of biological solids as well as additional settleable solids. Sludge produced in the advanced wastewater may consist of biological and chemical solid. Sludge is blended to produce a uniform mixture to downstream operations and process. Uniform mixtures are most important in short-detention-time systems, such as sludge dewatering, heat treatment, and incineration [31].

2.1.2 THICKENING:

Gravity thickening is the simplest and least expensive process for consolidating waste sludge [2]. Thickening is the practice of increasing solids content of sludge by the removal of a portion of its liquid content [1]. Thickeners in waste water treatment are employed most successfully in consolidating primary sludge separately or in combination with trickling filters. Water treatment wastes from both sedimentation and filter backwashing can be compacted effectively by gravity separation [2].

A modest increase in solids content can decrease total sludge volume, entailing size requirements for subsequent treatment units for subsequent treatment units. Sludge treatment methods are usually physical in nature: They include gravity settling, floatation, centrifugation and gravity belts [8].
With much flocculent sludge, particularly surplus activated sludge, slow speed stirring in a tank with a picket fence type mechanism encourages further flocculation and can significantly increase the solids content and settle ability. It is allowing supernatant to be drawn off [15].

2.1.3 STABILIZATION:

Sludge is stabilized to reduce their pathogen content, eliminate offensive odors, and reduce or eliminate the potential for putrefaction. Technologies used for stabilization include lime stabilization, heat treatment, aerobic digestion, anaerobic digestion and composting [6].

2.1.3.1 LIME STABILIZATION:

In this process lime is added to untreated sludge to raise the pH to 12 or higher. The high pH environment inhibits the survival of micro-organisms, and thus estimates the risk of sludge putrefaction and odor creation. Hydrated lime and Quick lime (CaO) are most commonly used for lime stabilization. Lime is added prior to dewatering or after dewatering [1]. Lime applied prior to primary clarification precipitates phosphates and hardness cations along with organic matter [2]. This will help in scale formation and phosphorus can be removed up to 95%.

The problem using this method is scale formation on tanks, pipes and other equipment, and disposal of the large quantity of lime sludge produced [2]. The major disadvantage of lime stabilization is that it is temporary [16]. Only operation of a full scale installation will reveal the significance of these possible troubles. The quantity of sludge produced is about 1.5 to 2 times than conventional method [12]. Lime stabilization and heat treatment are very less used [17].

Lime stabilization does not reduce the quantity of sludge, as biological stabilization.

The disadvantages are that relatively short time it can prevent biological activity and its lack of solids reduction [17].

2.1.3.2 HEAT TREATMENT:

The process involves the treatment of sludge by heating in a pressure vessel to temperature up to 260c at pressure up to 2760kN/mxm for approximately 30 seconds. The exposure of sludge to such conditions results in hydrolysis of proteinaceous compounds, leading to cell distribution and the release of soluble organic compounds and nitrogen [1]. The process also serves for conditioning, as the thermal activity releases bond water and results in the coagulation of solids.

The major disadvantages of heat treatment are its high energy requirement and the production of a high strength return liquid from the dewatering process [17].

2.1.4 ANAEROBIC DIGESTION:

The process involves the anaerobic reduction of organic matter in the sludge by biological activity [1]. Anaerobic digestion consists of two stages that occur simultaneously in digesting sludge. The first consist of hydrolysis of the high molecular weight organic compounds and conversion of organic acids by acid forming bacteria. The second stage is gasification of the organic acids to methane and carbon dioxide by the acid splitting methane forming bacteria [2].

2.1.5 COMPOSTING:

The objective of sludge composting is to biologically stabilize putrescible organics, destroy pathogenic organisms, and reduce the volume of waste [2]. During composting organic material undergoes biological degradation, resulting in a 20 to 30 percent reduction of volatile solids [5]. In composting, aerobic microorganisms convert much of the organic matter into carbon dioxide leaving a relatively stable odor free substance which has some value as a fertilizer [15]. Eccentric micro-organisms are also destroyed due to the rise in temperature of the compost. Composting includes the following operation:

1. Mixing dewatered sludge with a bulking agent.
2. Aerating the compost pile by mechanical turning or the addition of air.
3. Recovery of the bulking agent.
4. Further curing and storage.
5. Final disposal.

The resulting end product is stable and may be used as a soil conditioner in agricultural applications. Aerobic composting is more commonly used than anaerobic composting [1]. The aerobic composting process is exothermic and has been used at the household level as a means of producing hot water for home heating. The major advantage of this is compost is a very good fertilizer but it is not much used yet [16].

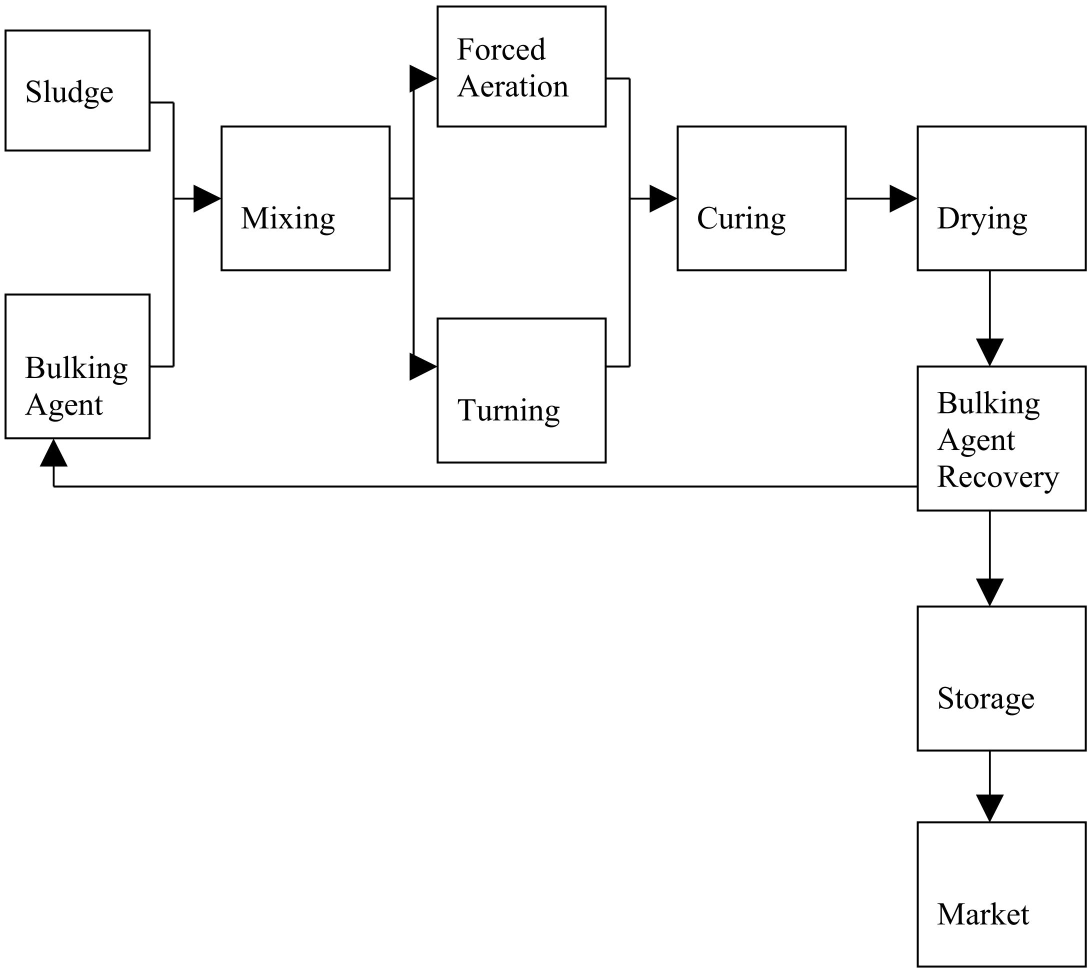

Figure 1: Composting Process Flow Diagram [1]

2.1.6 CONDITIONING:

Conditioning involves the chemical or physical treatment of sludge to enhance its dewatering characteristics. The two most applied conditioning methods are the addition of chemicals and heat treatment. Other conditioning processes include freezing, irradiation and elutriation [1].

2.1.7 DEWATERING:

Dewatering is a physical unit operation aimed at reducing the moisture content of sludge. Sludge is not incinerated or land applied it must be dewatered or dried. This can be achieved by applying sand beds or by using mechanical dewatering equipment [17]. The selection of appropriate sludge dewatering technique depends upon the characteristics of the sludge to be dewatered, available space and moisture content requirements of the sludge cake for ultimate disposal [1]. Dewatering may be improved by chemical conditioning, such as addition of a polymer [2][16]. When land is available and sludge quantity is small, natural dewatering systems such as drying beds and drying lagoons are most attractive. Mechanical dewatering methods include vacuum filter, centrifuge, filter press and belt filter press systems [1]. Sometimes sludge is contracted briefly under pressure by a hot surface. The steam generated at the interface between the sludge and the surface forces out some of the water in liquid form. This type of impulse drying is suitable when there is sufficient water available to build up steam pressure at the interface.

2.1.7.1 SLUDGE DRYING BEDS:

This is a method used for dewatering sludge when space is not a problem then we can use these type of methods as these type of methods are cheaper. Sand beds consist of a layer of sand with an under drain system. The sludge is pumped to the bed. Much of the water drains through the sand and is returned to the plant. The sun and wind dry the material further [17] [1] [2].

2.1.7.2 DRYING LAGOONS:

Sludge drying lagoons which are suitable only for the treatment of digested sludge, consist of shallow earthen basins enclosed by earthen dykes. The sludge is first placed in the basin and allowed to dry. The supernatant is decanted from the surface and returned to the plant while the liquid is allowed to evaporate. Mechanical equipment is then used to remove the sludge cake [1] [2].

2.1.8 FILTRATION

2.1.8.1 Pressure Filtration:

It is batch process in which conditioned sludge is pumped with increasing pressure into chambers lined with cloths or membranes which retain the solids but allow liquid to escape via grooves in the metal backing plates. A liquid escapes, the cake formed adjacent to the cloth or membrane acts as a further filter for the remainder of the sludge so that the cake dewaters towards the centre. Solids loading depend upon the nature of the sludge and the length of pressing cycle.

A filter belt press provides continuous operation by introducing conditioned sludge via gravity or vacuum assisted drainage section into the gap between two endless belts to which pressure is applied by means of rollers. Dewatering occurs by a combination of gravity drainage, pressure filtration and shear [15]. This process is quite famous in Europe but not in U.S. its principle advantage over vacuum filter is the ability to achieve a drier cake. Hydraulic presses have also been applied to further dewater filter cake from paper mill sludge for incineration [18] [16] [2].

2.1.8.2 Vacuum Filtration:

The vacuum filtration process is used for dewatering both raw and digested wastewater sludge. The vacuum filtration process consists of a horizontal cylindrical drum that is partially submerged in a tank of conditioned sludge. The surface of drum is covered with a pours medium (cloth belts or coiled springs) and is divided into sections around its circumference. As the drum rotates the sections function in sequence as three distinct zones cake formation, cake dewatering and cake discharge [1]. Vacuum is maintained inside the drum and draws the sludge to the filter medium [2]. A vacuum of 90kPa is applied to the submerged segments and sludge is attracted towards the surface of cloth. As the drum rotates and the layer of sludge emerges from the tank, air is drawn through it by vacuum to assist dewatering. A scrapper blade removes the sludge cake assisted by change to positive pressure in the relevant drum segment [15] [17].

2.1.8.3 Belt Filter Press:

A belt filter press compresses the sludge between two endless porous belts tensioned over a series of rollers to squeeze out the water [2].

The filtration process involves four basic stages.

1. Polymer conditioning zone.
2. Gravity drainage zone for excess water.
3. Low pressure zone.
4. High pressure zone.

Filtration Stage	Description
Polymer Conditioning zone	Consist of a tank located close to the press, a rotating drum attached to the press, or an inline injector.
Gravity drainage zone	Consist of a flat or slightly inclined belt. Sludge is thickened by the gravity drainage of free water. This section may be vacuum assisted.
Low pressure zone	This is the area where the upper and lower belts come together with sludge in between. It prepares the sludge by forming a firm sludge cake that is able to withstand the shear forces within the high pressure zone.
High pressure zone	In this stage, forces are exerted on the sludge by the movement of the upper and lower belts relative to each other, as they go over and under a series of rollers with decreasing diameters. The resulting sludge cake is removed by scrapper blades.

Table 2: Belt Filtration Table

The machines are quite effective in dewatering many different types of sludge and are being installed in many small waste water treatment plants [16] [1] [2].

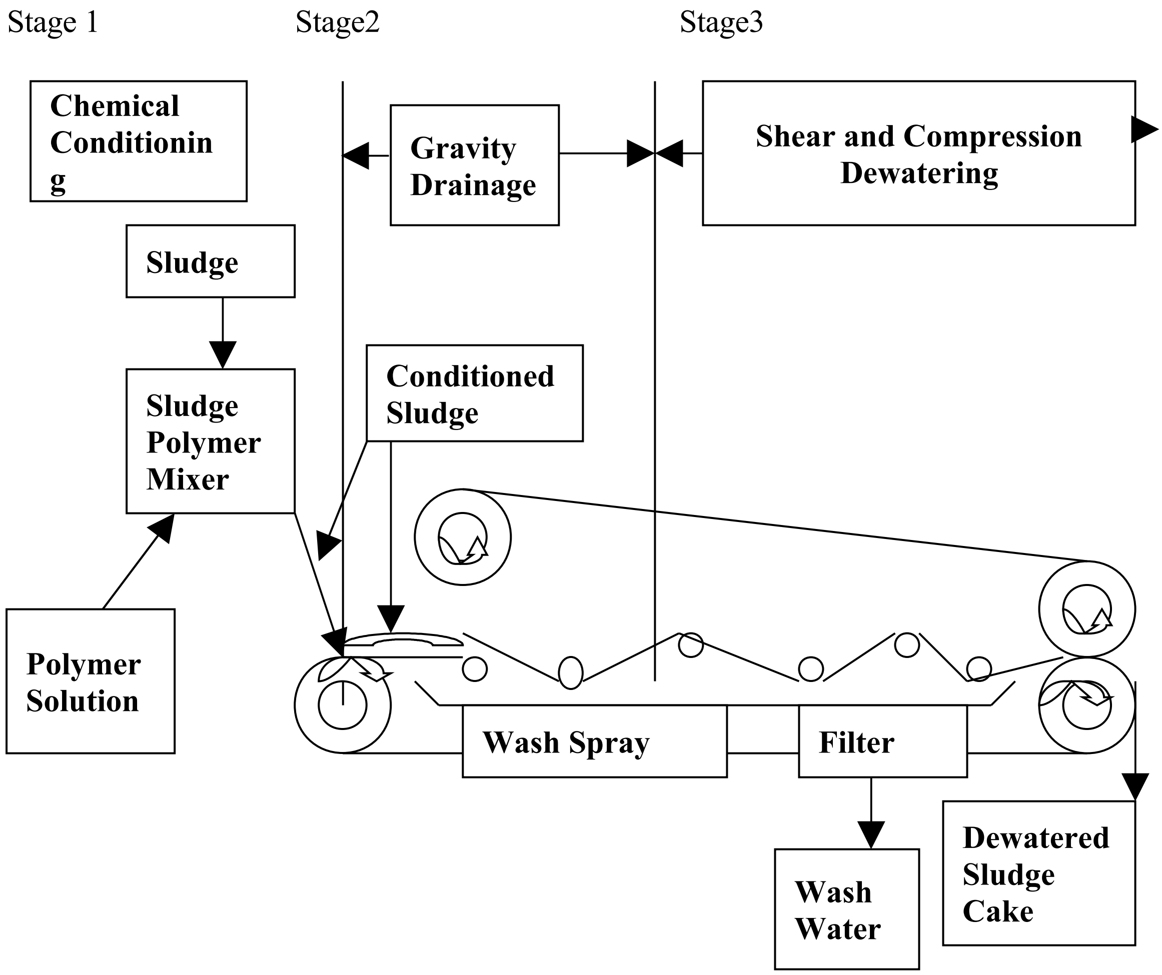

Figure 2: Belt Filter Press [1]

2.1.9 DRYING:

The purpose of sludge drying is to reduce the water content to less than 10 percent by evaporation, making sludge suitable for incineration or processing into fertilizer. Small communities use open air drying due to its simplicity [2]. Commercially drying is performed mechanically by the application of auxiliary heat. In open air drying disadvantages are poor drying during dump weather, potential odor problems, large land area required, and labor for removing the dried cake [15] [1] [2].

3. Methodology:-

In the study, a survey was carried out at Scottish Water treatment plant and Cathkin near to Carmunnock Village in South Lanarkshire for the case study of waste water sludge treatment to compare the three technologies for sludge disposal.

1) Anaerobic Digestion
2) Aerobic Digestion
3) Landfills.

3.1 Anaerobic Digestion:-

Anaerobic digestion is a bacterial decomposition process that stabilizes organic wastes and produces a mixture of methane and carbon dioxide gas (biogas). The calorific value of methane is the same as natural petroleum gas, and biogas is valuable as an energy source. Anaerobic digestion is typically carried out in a specially built digester, where the content is mixed and the digester maintained at 35 degree C by combusting the biogas produced. After digestion the sludge is passed to a sedimentation tank where the sludge is thickened. Biogas is collected from the digester. The thickened sludge requires further treatment earlier to reuse or disposal.

Anaerobic digestion can also be carried out at a slower rate in an unmixed tank or pond. Covering is usually by a UV resistant plastic sheet, because of the large area needed to be covered, and biogas is collected from the top of the sheet. Storage of biogas can be in a cylindrical tank with a floating roof. The cylindrical roof floats on water and its position is determined by the volume of the gas stored under the pressure of the roof. Biogas can be stored in a balloon only under low pressure [1].

The process involves the anaerobic reduction of organic matter in the sludge by biological activity [1]. Anaerobic digestion consists of two stages that occur simultaneously in digesting sludge. The first consist of hydrolysis of the high molecular weight organic compounds and conversion of organic acids by acid forming bacteria. The second stage is gasification of the organic acids to methane and carbon dioxide by the acid splitting methane forming bacteria [2].

Anaerobic digestion treatment of sludge will decrease the volatile organics by 40 to 50% and reduce the numbers of pathogenic organics in sludge. Traditional methods are accomplished by holding the sludge in closed tanks for periods of 10 to 90 days. Older version of anaerobic digestion used unheated, unmixed tanks. This results in very long detention time 30 to 90 days. However more recent processes involve complete mixing and heating to temperatures of 35 to 40 centigrade, reducing detention time up to 10 to 20 days [17].

The advantages of anaerobic digestion include the production of usable energy in the form of methane gas. Low solid production, very low energy input.

Disadvantage includes very high capital costs, susceptibility to upsets from shock loads or toxics, and complex operation requiring skilled operators [17].

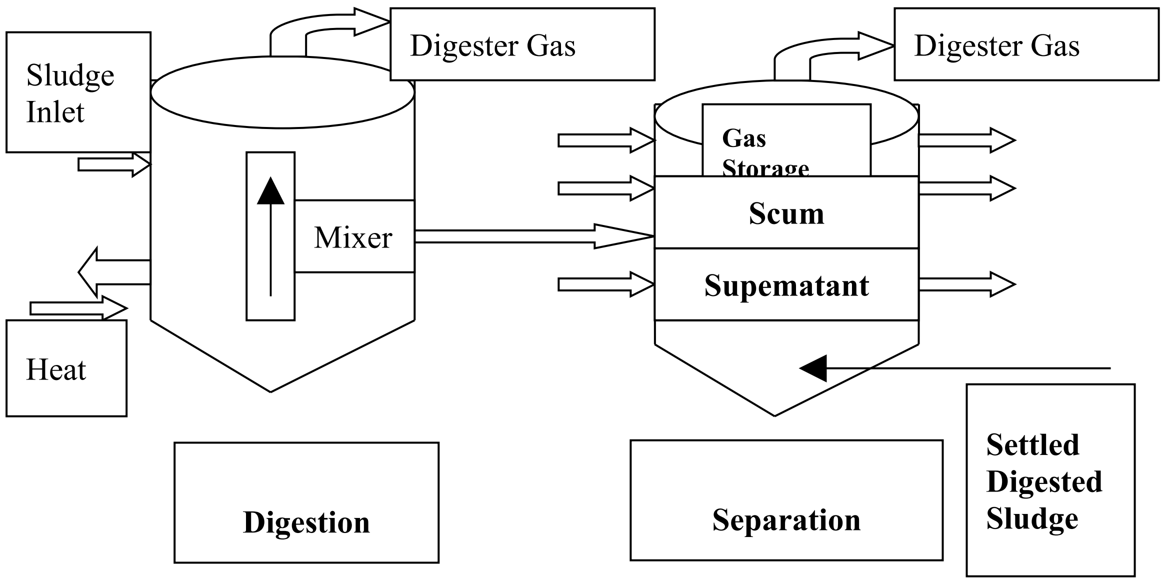

Figure 3: Complete mix, or high rate, anaerobic digester [17]

The cross section of a floating cover digestion tank is shown in fig. raw sludge is pumped into the digester through pipes terminating either near the centre of the tank or in the gas dome. Pumping sludge into the dome helps to break up the scum layer that forms on the surface.

Digested sludge is withdrawn from the tank bottom. The contents are heated in the zone of digesting sludge by pumping then through the inlet lines. The tank contents stratify with a scum layer on the top and digested thickened sludge on the bottom. The middle zone consist of a layer of supernatant (water of separation) underlain by the zone of actively digesting sludge. Supernatant is drawn from the digester through any one of a series of pipes extending out of the tank wall. Digestion gas from the gas dome is burned as fuel in the external heater or wasted to a gas burner. Output gas can be collected at the ceiling of the dome.

3.1.1 Application of Anaerobic Digestion:

Activated sludge is resistant to anaerobic digestion. The cell contents are very degradable but they are protected by the tough cell walls. Biomass also holds onto water, so it is difficult to dewater. Ultrasound cracks open the cells so that contents are available for Ad (Anaerobic Digestion) to metabolize them. Biogas yielding can be increased by 30% by AD. It can cure the problem of digested cake odour, which can be the bane of biosolids recyclers' lives [3].

3.1.2 Anaerobic Contact Process

Some industrial wastes that are high in BOD can be stabilised very efficiently by anaerobic treatment. In the anaerobic contact process, untreated wastes are mixed with recycled sludge solids and then digested in a reactor sealed to the entry of air. The contents are mixed completely. After digestion, the mixture is separated in a clarifier or vacuum flotation unit, and the supernatant is discharged as effluent, usually for further treatment. Settled anaerobic sludge is then recycled to seed the incoming waste water. Because of the low synthesis rate of anaerobic microorganisms, the excess sludge that must be disposed of is minimal [31].

3.1.3 Anaerobic Attached-Growth Treatment Processes

The most common anaerobic attached growth treatment process is the anaerobic filter process used for the treatment of both domestic and industrial wastes [31].

3.1.3.1 Anaerobic Filter

The anaerobic filter, a relatively recent development in the field of wastewater treatment, is a column filled with various types of solid media used for the treatment of the carbonaceous organic matter in wastewater. The waste flows upward through the column, contacting the medium on which anaerobic bacteria grow and are retained.

Because the bacteria are retained on the medium and not washed off in the effluent, mean cell residence times on the order of 100 days can be obtained [31].

3.1.3.2 Anaerobic ponds

Anaerobic ponds are used for the treatment of high-strength organic wastewater that also contains a high concentration of solids. Typically an anaerobic pond is a deep earthen pond with appropriate inlet and outlet piping. To conserve heat energy and to maintain anaerobic conditions, anaerobic ponds have been constructed with depths up to 6.1 m (10 ft.). The wastes that are added to the pond settle to the bottom. The partially clarified effluent is usually discharged to another treatment process for further treatment [31].

3.2 Aerobic Digestion:-

Aerobic digestion sludge process is similar to the activated sludge process. The function of aerobic digestion is to stabilize waste sludge solids by long term aeration, thereby reducing BOD and destroying volatile solids [2]. It involves the direct oxidation of biodegradable matter and microbial cellular material in open tanks for an extended period of time. In aerobic treatment the sludge is aerated for an extended time typically 12 to 20 days [2]. During this time of duration this amount of time biological material is reduced to about half its original amount. Aeration seems either naturally or by means of mechanical aerators and diffusers [1]. Long term aeration of waste sludge creates a bulking material that resists gravity thickening [2].

Advantages of aerobic digestion:

- Volatile solids reduction approximately the same as anaerobic digestion
- Supernatant liquor with lower BOD concentrations.
- Production of an odor less, humans like, biologically stable end product.
- Recovery of most of the basic fertilizer values in the sludge.
- Operation relatively easier.
- Lower capital cost.

Disadvantage:

- Higher power cost associated with supplying oxygen.
- Produces a digested sludge with poor mechanical dewatering characteristics.

- The process is significantly affected by temperature, location and type of tank.
- High operating cost.

3.2.1 AEROBIC DECOMPOSITION:

A biological process, in which, organisms use available organic matter to support biological activity. The process uses organic matter, nutrients, and dissolved oxygen, and produces stable solids, carbon dioxide, and more organisms. The microorganisms which can only survive in aerobic conditions are known as aerobic organisms. In sewer lines the sewage becomes anoxic if left for a few hours and becomes anaerobic if left for more than 1 1/2 days.

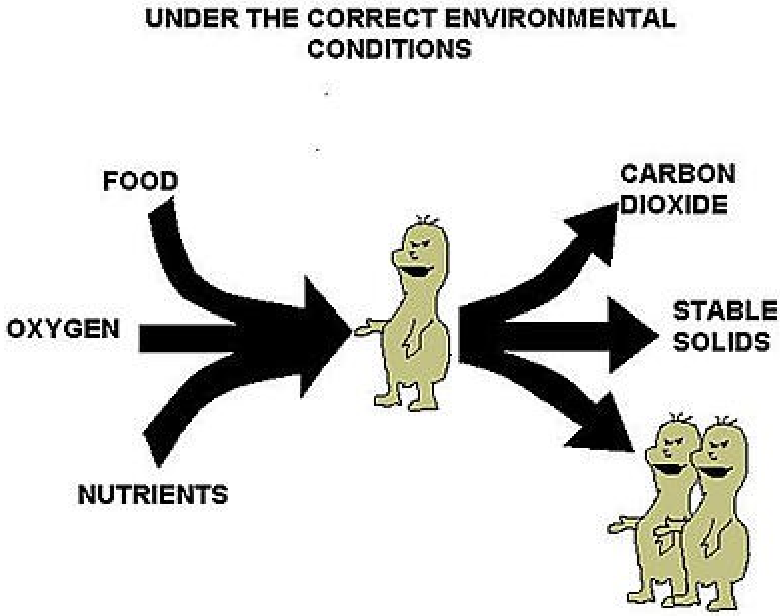

Figure 4: Process of Aerobic Digestion [20]

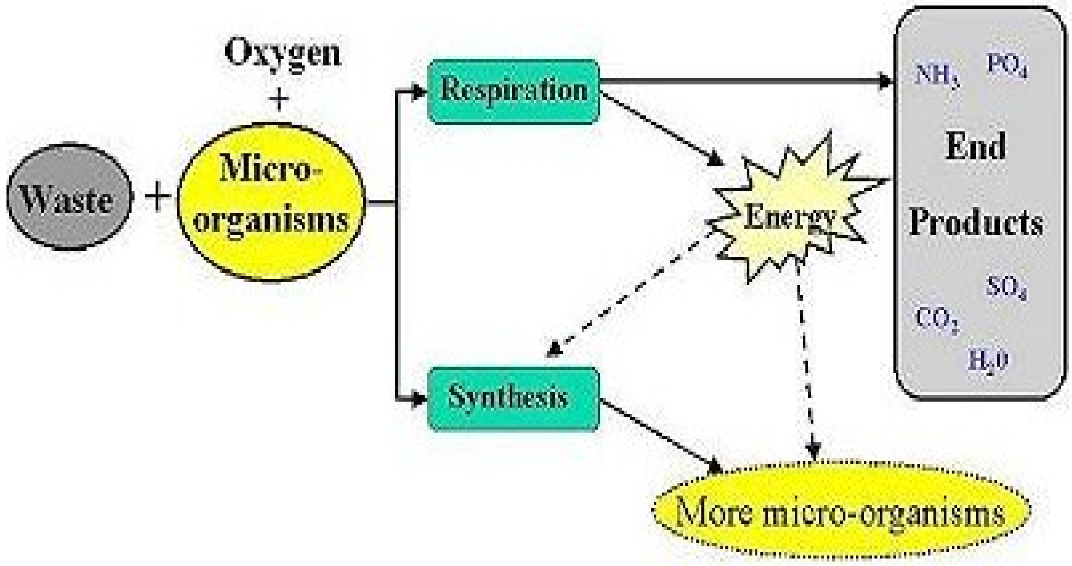

Figure 5: PATH of aerobic digestion [20]

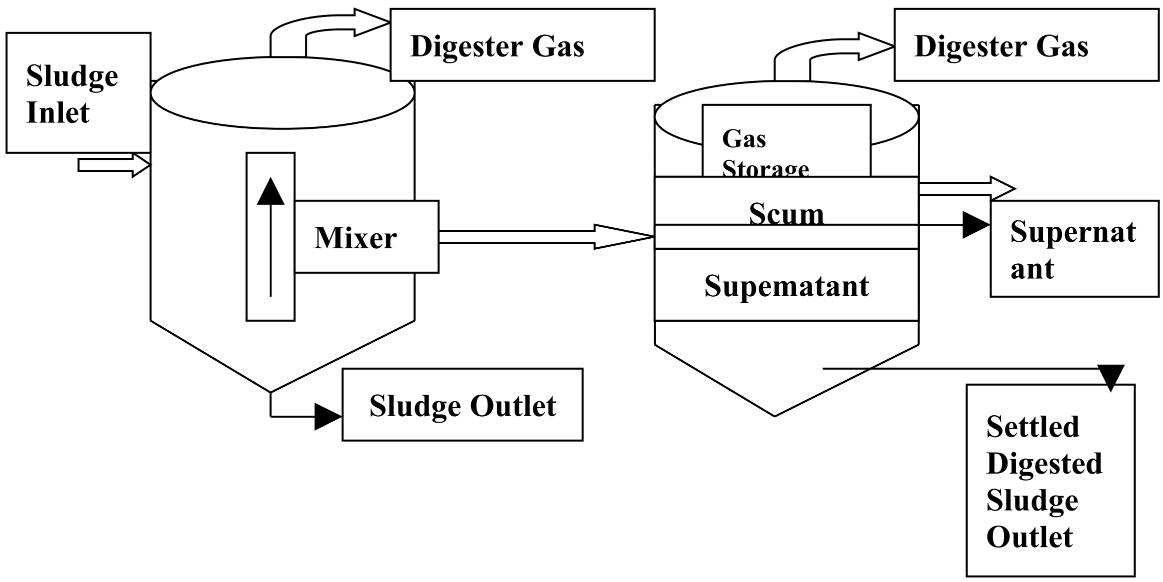

Figure 6: Two stage Digester [1]

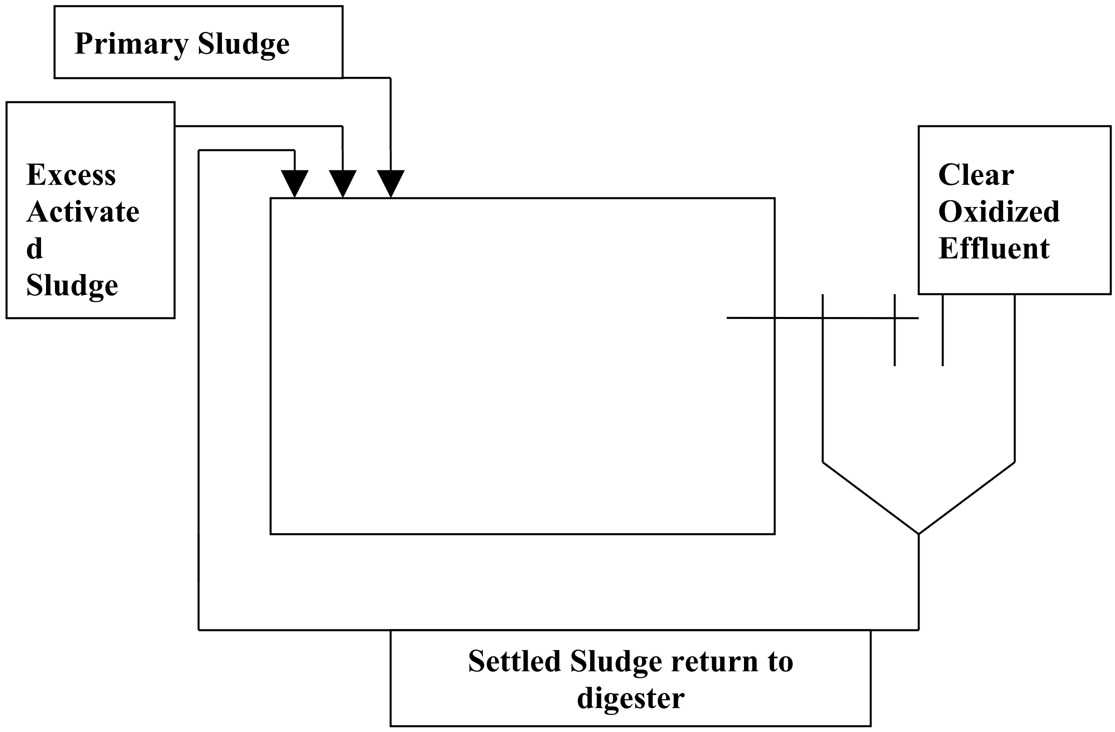

FIGURE 7: SCHEMATIC OF AEROBIC SLUDGE DIGESTION [1]

3.2.2 Process Description:

Aerobic digestion is similar to the activated-sludge process. As the supply of available substrate is depleted, the microorganisms begin to consume their own protoplasm to obtain energy for cell-maintenance reactions. When this occurs, the microorganism are said to be in the endogenous phase. Cell tissue is oxidized aerobically to carbon dioxide, water and ammonia. In actuality only about 75 to 80 percent of the cell tissue can be oxidized; the remaining 20 to 25 percent is composed of inert components and organic compounds that are not biodegradable. The ammonia from this oxidation is subsequently oxidized to nitrate as digestion proceeds [8].

A pH drop can occur when ammonia is oxidized to nitrate if the alkalinity of the waste water is insufficient to buffer the solution. Theoretically, about 7.1 kg of alkalinity are destroyed per kilogram of ammonia oxidized. In situation where the buffer capacity is insufficient, it may be necessary to install chemical feed equipment to maintain the desired pH. Where activated or trickling-filter sludge is mixed with primary sludge and the combination is to be aerobically digested, there will be both direct oxidation of the organic matter in the primary sludge and endogenous oxidation of the cell tissue. Aerobic digesters can be operated as batch or continuous flow reactors [8].

At present, two proven variations of the process are available:

i. Conventional Aerobic Digestion

ii. Pure-oxygen Aerobic Digestion.

A third variation, thermophilic aerobic digestion, is currently under intensive investigation.

3.2.2.1 Conventional-Air Aerobic Digestion:

Factors that must be considered in designing aerobic digesters include hydraulic residence time, process loading criteria, oxygen requirements, and energy requirements for mixing, environmental conditions and process operation.

a) Hydraulic residence time:

The amount of volatile solids in sludge is reduced more or less linearly up to a value of about 40 percent at a hydraulic detention time of about 10 to 12 d [8]. Although volatile-solids removal continues with increasing detention time, the rate of removal is reduced considerably. Depending on the temperature, the maximum reduction ranges between 45 and 70 percent. The required time and degree of volatile-solids removal also varies with the characteristics of the sludge. Typically, volatile-solids reductions vary from about 35 to 45 percent in 10 to 12 days at temperature equal to or above 20 degree C [8].

b) Loading Criteria:

Limited information is currently available on appropriate loading criteria to use for this process. Loading criteria based on mean cell residence time would appear to be most satisfactory. The maximum solids concentration would be governed by oxygen-transfer and mixing requirements. If only waste activated sludge is to be aerobically digested, the mean cell residence time required to achieve a given volatile-solids reduction can be estimated [8].

c) Oxygen Requirement:

The oxygen requirements that must be satisfied during aerobic digestion are those of the cell tissue and, with mixed sludges, the BOD in the primary sludge. The oxygen requirement for the complete oxidation of cell tissue is equal to 7 mol/mol of cells, or about 2 kg/kg of cells. The oxygen requirement for the complete oxidation of the BOD contained in primary sludge varies from about 1.7 to 1.9 kg/kg destroyed. On the basis of operating experience, it has been found that if the dissolved oxygen concentration in the digester is maintained at 1 to 2 mg/L and the detention time is greater than 10 days, the sludge dewaters well [8].

d) Energy requirements for mixing:

To ensure proper operation, the contents of the aerobic digester should be well mixed. In general, because of the amount of air that must be supplied to meet the oxygen requirement, mixing should be achieved; nevertheless, power mixing requirements should be checked.

e) Environmental Conditions:

Temperature and pH plays an important role in the operation of aerobic digesters. It has been observed that the operation of aerobic digesters is temperature-dependent, especially at temperature below 20 degree C. On the basis of extremely limited data, it appears that a temperature coefficient in the range of 1.08 to 1.10 might be appropriate for adjusting the hydraulic detention time for temperatures below 20 degree C for hydraulic residence times on the order of 15 days. As the hydraulic detention time is increased to about 60 days, the effect of temperature is negligible. In extreme cold climates, consideration should be given to heating the sludge or the air supply, covering the tanks or both.

Depending on the buffering of the system, the pH may drop to a rather low value (5.5) at long hydraulic detention times. Reasons advanced for this include the increased presence of nitrate ions in solution and the lowering of the buffering capacity due to air stripping [8]. Although this does not seem to inhibit the process, the pH should be checked periodically and adjusted if found to be excessively low.

f) Process Operation:

In the past, aerobic digestion has normally been conducted in unheated tanks similar to those used in the activated-sludge process. However, as understanding of the thermophilic aerobic digestion process increases, it is anticipated that more use will be made of well-insulated or even partially heated tanks. In some cases, existing anaerobic digesters have been converted and are being used as aerobic digesters. Aerobic digester should be equipped with decanting facilities so that they may also be used to thicken the digested solids before discharging them to subsequent thickening facilities or sludge-drying beds. If the digester is operated so that the incoming sludge is used to displace supernatant and the solids are allowed to build up, the mean cell residence time will not be equal to the hydraulic residence time.

3.2.2.2 Pure-Oxygen Aerobic Digestion:

Pure-oxygen Aerobic digestion is a modification of the aerobic digestion process in which pure oxygen is used in lieu of air. The resultant sludge is similar to sludge from conventional-air aerobic digestion. Influent sludge concentrations vary from 2 to 4 percent. Recycle flows are similar to those achieved by conventional-air aerobic digestion. Pure-oxygen aerobic digestion is particularly applicable in cold weather climates because of its relative insensitivity to ambient air temperatures. This modification is an emerging technology that is currently being investigated in several full scale installations.

In one configuration being investigated, a covered aeration tank is used. In this variation, a high purity-oxygen atmosphere is maintained above the liquid surface, and oxygen is transferred into the sludge via mechanical aerators. In another variation, an open aeration tank is used. Oxygen is introduced to the liquid sludge by a special diffuser that produces minute oxygen bubbles. The bubbles totally dissolve before reaching the air-liquid interface.

The aerobic process is exothermic. Normally, the heat generated is not retained in conventional-air aerobic digesters because of the vigorous aeration in the open tank. Temperatures of the digesting sludges were maintained above ambient air temperature in the pure-oxygen investigations because the increased gas transfer allows the heat to be retained and the sludge temperatures to rise. This effect is more pronounced in the covered tank. Maintenance of these higher temperatures in the digesters results in a significant increase in the rate of volatile suspended solids destruction [9].

Pure-oxygen aerobic digestion can be used only by large installations when the incremental costs of oxygen-generation equipment is offset by the savings obtained by reduced rector volumes and lower energy requirements for dissolution equipments. In this regard, the process is most compatible with a treatment facility using the pure-oxygen activated-sludge process, because of the potential for oxygen availability on an incremental basis.

3.2.2.3 Thermophilic Aerobic Digestion:

Thermophilic aerobic digestion represents a refinement of both the conventional-air and pure-oxygen aerobic digestion. Although there are presently no full scale installations, it has been shown in large scale pilot studies that thermophilic aerobic digestion can be used to achieve high removals of the biodegradable fraction (up to 70 percent) at very short detention times (3 to 4 days). Thermophilic digestion without external heat input can be achieved by using the heat released during microbial oxidation of organic matter to heat the sludge. It has been estimated that more than 25 kcal/L of heat energy are released in the aerobic digestion of primary and secondary sludges (between 2 and 5 percent) [10]. It has also been demonstrated that this quality of heat is sufficient to heat wet slurries containing from 95 to 97 percent water to the thermophilic range 45 degree C if sufficiently high oxygen transfer efficiencies can be obtained so that air or oxygen stripping of the heat does not occur [10].

Although it would appear that pure oxygen would be best in this application, it has been shown that thermophilic digestion can be achieved with a simple air aeration system. Typically, the process operates from 25 to 50 degree C above the ambient air temperature [10]. Because of high operating temperatures, the digested sludge is pasteurized as well. Ideally, the feed sludge should contain more than 4 percent solids to optimally support thermophilic digestion.

3.3 Land Application of Sludge:

Land application is defined as the spreading, spraying, injection, or incorporation of sewage sludge, including a material derived from sewage sludge (e.g., compost and palletized sewage sludge), onto or below the surface of the land to take advantage of the soil enhancing qualities of the sewage sludge. Sewage sludge is land applied to improve the structure of the soil. It is also applied as a fertilizer to supply nutrients to crops and other vegetation grown in the soil. Sewage sludge is commonly applied to agricultural land (including pasture and range land), forests, reclamation sites, public contact sites (e.g., parks, turf farms, highway median strips and golf courses), lawns, and home gardens [11].

Sewage sludge is land applied in bulk form or sold or given away in a bag or similar container for application to the land. The term "bulk" implies sewage sludge that is applied generally in large quantities to large parcels of land. Bulk sewage sludge is typically used by commercial and municipal appliers for agriculture, tree and turf farms, golf courses, parks, and reclamation of construction or surface mining sites. Sewage sludge sold or given away in a bag or other container is generally used by the smaller scale user, such as a home gardener or landscaper [11].

In disturbed areas such as mining sites, where there is no soil substrate from which to sustain vegetation, large amounts of nitrogen and organic material may be required to re-establish basic plant cover. When sewage sludge is used in these areas to supply the adequate substrate, it is often necessary to apply quantities that exceed the Agronomic Rate (The whole sludge application rate designed to (1) provide the amount of nitrogen needed by a crop or vegetation grown on the land and (2) minimize the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the ground water).

In such cases, sewage sludge is generally applied once, and then the site is seeded. Because of the highly soluble nature of nitrates, which are the main nutritive component of both sewage sludge and standard fertilizer products, sewage sludge applied in this manner has the potential for nitrate contamination of ground water if not properly managed. Therefore, any time sewage sludge is going to be applied at greater than agronomic rates, the land applier must first seek approval from the permitting authority. In some instances, the permitting authority may require a specific permit for this practice. Domestic septage also contains beneficial characteristics as a soil enhancer and can be land applied. Although domestic septage is considered sewage sludge, its physical characteristics are different from those of sewage sludge generated at a wastewater treatment plant.

Surface disposal is another regulated use or disposal practice for sewage sludge that is similar to land application in that it entails the placement of sewage sludge on the land. The main difference between the two is that in the case of surface disposal, sewage sludge is placed on the land for the purpose of final disposal, without regard for the soil enhancing qualities of the sewage sludge [11].

3.3.1 Sewage Sludge Quality

To determining sewage sludge quality it depends on three following parameters:-

- The presence of pollutants (arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc)
- The presence of pathogens (e.g., bacteria, viruses, parasites)
- The sewage sludge's attractiveness to vectors (e.g., rodents, flies, mosquitoes).

Sewage sludge quality varies from municipality to municipality with respect to these three parameters. Determining sewage sludge quality is usually the sole responsibility of the person who initially prepares the sludge, and not of the land applier. However, because sewage sludge quality plays such a significant role in determining land application requirements, a portion of this document is dedicated to the explanation of this topic.

Sewage sludge that meets the most stringent limits for all three of the above sewage sludge quality parameters is referred to as Exceptional Quality (EQ) sewage sludge. Sewage sludge that does not meet the most stringent limits for any or all three of the sludge quality parameters is referred to as non-EQ sewage sludge. EQ sludge is considered comparable to standard fertilizer products. Therefore land appliers of EQ sewage sludge have no requirements to meet under the Rule [11].

3.3.2 Methods of Sewage Sludge Distribution to the Land Applier:-

The number and type of requirements associated with the land application of sewage sludge are affected not only by sludge quality (pollutant levels, level of pathogen reduction, and attractiveness to vectors), but also by the method of distribution, that is, whether the sludge is applied in bulk form or is placed in a bag or other container for application to the land. The method of distribution is important because it is an indication of the relative quantity of sewage sludge being applied. Bulk sewage sludge is usually applied in large quantities, whereas sewage sludge sold or given away in bags or other containers is usually applied in smaller quantities. Some types of requirements can be easily implemented by large quantity land appliers, while the same requirement can be impractical and cumbersome for the small quantity appliers.

Appliers of sewage sludge sold or given away in a bag or other container need only read and adhere to instructions on the label or information sheet accompanying the sewage sludge product; they are not subject to management practices, pollutant limits, pathogen and vector attraction reduction requirements, or recordkeeping and reporting requirements. Because the probability of close human contact is very high when sewage sludge is distributed for use by the general public in bags or other containers, only material that is EQ for all three sludge quality parameters, or that at a minimum meets EQ quality for pathogen reduction and vector attraction reduction, can be distributed in bags or other containers [12].

Sewage sludge that does not attain EQ quality for at least these two parameters can only be distributed and applied in bulk. This is because there are a number of site restrictions and other land application requirements that are necessary for the proper application of sewage sludge of this quality yet would be impractical for small appliers such as homeowners to implement.

3.3.3 Consequences of Changing the Quality of Sewage Sludge:-

If the applier changes the quality of the sewage sludge prior to application, the change may influence the number of requirements with which the land applier must comply.
Generally, it is the responsibility of the person who prepares the sewage sludge to monitor and certify sewage sludge quality. In some cases, the person who prepares the

sewage sludge also land applies it and is clearly responsible for meeting the requirements for sewage sludge preparation in addition to those for land application. If the land applier alters the sewage sludge quality so that the quality of the sewage sludge being applied is different from what was received from the preparer, the land applier becomes a preparer and assumes responsibility for monitoring and certifying its quality (e.g., certification of sludge quality relative to pollutant limits, level of pathogen reduction, and level of vector attraction reduction). Mixing bulk EQ sewage sludge with other EQ sewage sludges, can corn posting it, or mixing it with other substances such as bulking agents, wood chips, or substances to enhance the beneficial characteristics of the sludge as a fertilizer theoretically results in a mixture that is still EQ in quality. Therefore, in these situations, the land applier would not assume responsibility for re-evaluating its quality.

However, sludge quality is considered to have been changed when bulk non-EQ sewage sludge is accepted from several sources and mixed prior to land application, when bulk non-EQ sewage sludge is mixed with other additives such as wood chips\bulking agents or substances to enhance the characteristics of sludge as a fertilizer, or when bulk EQ sewage sludge is mixed with non-EQ sludge. In these situations, the resulting quality of the mixtures must be ascertained to know, how to correctly land apply [12].

3.3.4 Pollutant Limits of Sewage Sludge:-

The first parameter of the three that must be assessed to determine overall sludge quality is the level of pollutants (metals). Some sewage sludge contains negligible levels of pollutants while others contain higher levels. To ensure that human health and the environment are protected equally while still allowing the land application of sewage sludges of variable quality, now four sets of pollutant limits are described as follows:

3.3.4.1 Ceiling Concentrations of Sewage Sludge:-

Ceiling concentrations apply to all land applied sewage sludge (bulk sewage sludge and sewage sludge sold or given away in a bag or other container). Ceiling concentrations (milligrams per kilogram, on a dry weight basis), establish the maximum concentration of each pollutant that sewage sludge can contain and still be land applied. Each sample of sewage sludge analyzed must meet the ceiling concentration limits. These limits are applied as maximum, never to be exceeded values, not as averages. Sewage sludge that does not meet these specified thresholds for any or all of the 10 regulated pollutants must be used of disposed of in some other way; it cannot be land applied. Once it is determined that sewage sludge meets ceiling concentrations, the preparer must determine which one of the remaining three sets of pollutant limits applies to his or her sewage sludge [12].

Concentration Limits		
Pollutant	**Ceiling Concentrations (milligrams per kilogram, dry weight)**	**Pollutant Concentrations Monthly Average (milligrams per kilogram, dry weight)**
Arsenic	75	41
Cadmium	85	39
Chromium	3,000	1,200
Copper	4,300	1,500
Lead	840	300
Mercury	57	17
Molybdenum	75	--
Nickel	420	420
Selenium	100	36
Zinc	7500	2,800

Table3: Pollutant Limits for the Land Applications of Sewage Sludge [12]

3.3.4.2 Pollutant Concentration Limits for Sewage Sludge:

Sewage sludge meeting pollutant concentration limits achieves one of three levels of quality necessary for EQ status. The land applier has no land application requirements relative to pollutants for sewage sludge meeting these limits. Pollutant concentration limits are monthly average values in milligrams per kilogram on a dry weight basis (see Table 1 above).

Loading Rates				
	Cumulative Pollutant Loading Rates		Annual Pollutant Loading Rates	
Pollutant	(kilogram per hectare, dry weight)	(pounds per acre, dry weight)	(kilograms per hectare per 365-day period, dry weight)	(pounds per acre per 365-day period, dry weight)
Arsenic	41	37	2.0	1.8
Cadmium	39	35	1.9	1.7
Chromium	3,000	2,677	150	134
Copper	1,500	1,339	75	67
Lead	300	268	15	13
Mercury	17	15	0.85	0.76
Molybdenum	--	--	--	--
Nickel	420	375	21	19
Selenium	100	89	5.0	4.5
Zinc	2,800	2,500	140	125

Table 4:- Loading rates [12]

3.3.4.3 Cumulative Pollutant Loadings

CPLRs apply to bulk sludge that meets ceiling concentration limits but does not meet pollutant concentration limits for any or all of the 10 regulated pollutants (see Table 2).

Cumulative pollutant loading rate (CPLR): - The maximum amount of an inorganic pollutant that can be applied to an area of land. This term applies to bulk sewage sludge that is land applied. CPLRs establish the maximum amount (mass) of each regulated pollutant that can be applied to a site (kilogram per hectare) during the life of the site. (For purposes of determining compliance, a "site" is considered to be a parcel of land on which sewage sludge has been or will be applied.) The greatest number of recordkeeping and reporting requirements for the land applier pertains to sewage sludge of this quality [12].

When applying sewage sludge that is subject to CPLRs, the land applier is required to keep records of the amounts of each regulated pollutant applied to the site over time to ensure that the maximum allowable amounts are not exceeded. This is calculated by determining the amount of each pollutant applied to the land in previous sewage sludge applications and subtracting this amount from the CPLR for each pollutant. The applier then must maintain records of the amounts of each pollutant applied to the site in sewage sludge, including the amounts applied in previous applications occurring after July 20, 1993. If several land appliers are applying sewage sludge on the same site, all the land appliers are responsible for communicating with each other to ensure that the CPLRs are not exceeded [12].

3.3.4.4 Annual Pollutant Loading Rates

APLRs apply to sewage sludge that meets ceiling concentrations, but does not meet pollutant concentration limits (see Table 2), and is to be sold or given away in a bag or other container for application to the land. APLRs establish the maximum amount (mass) of pollutants in sewage sludge that can be applied to a site during a 365-day period. APLRs instead of CPLRs are applied to these sludges because sewage sludge sold or given away in a bag or other container is commonly used by homeowners and it would be impractical to expect homeowners to track cumulative pollutant loadings. APLRs, therefore, have been designed so that the applier of bagged sewage sludge of this quality does not have to track cumulative pollutant loadings [12].

Appliers that use sewage sludge sold or given away in a bag or other container have no requirements except to follow the instructions provided with the sewage sludge. For non-EQ sewage sludge that is sold or given away in a bag or other container, the person who prepares the sewage sludge is required to determine the appropriate application rate based on the sludge quality and print it on a label or information sheet for the applier.

Note that only EQ sewage sludge or sewage sludge that is non-EQ only due to pollutant levels can be sold or given away in a bag or other container. Bagged sewage sludge must, at a minimum, meet the highest quality requirements for pathogen reduction and one of the eight vector attraction reduction options that involve treatment of the sewage sludge. Sewage sludge that does not meet the highest quality for at least these two sludge quality parameters cannot be sold or given away in a bag or other container for application to the land [12].

3.3.4.5 Pathogen Reduction:-

The second parameter in determining sewage sludge quality is the presence or absence of pathogens (i.e., disease causing organisms), such as Salmonella bacteria, enteric viruses, and viable helminth ova. The preparer is responsible for monitoring and certifying the sewage sludge for pathogen reduction. If the land applier chooses, however, he or she may at any time verify this information independently.

Pathogen reduction contains two classes. Class A and Class B. Class A pathogen reduction alternatives render the sewage sludge virtually pathogen free after treatment. Class B pathogen reduction alternatives significantly reduce but do not eliminate all pathogens. Land appliers who apply sewage sludge that is certified by the preparer as Class A have no requirements relative to pathogens. If the sewage sludge is Class B, site restrictions must be imposed to allow time for natural processes to further reduce pathogen levels.

Site restrictions for Class B address (1) public access to the land application site and (2) crop harvest and grazing of animals at the site. Public access must be restricted for at least 30 days on all land application sites that receive Class B sewage sludge.

If the site is frequently used by the public or the potential for public contact is high, public access must be restricted for 1 year after Class B sewage sludge is applied. Picture below illustrates the different public access waiting periods.

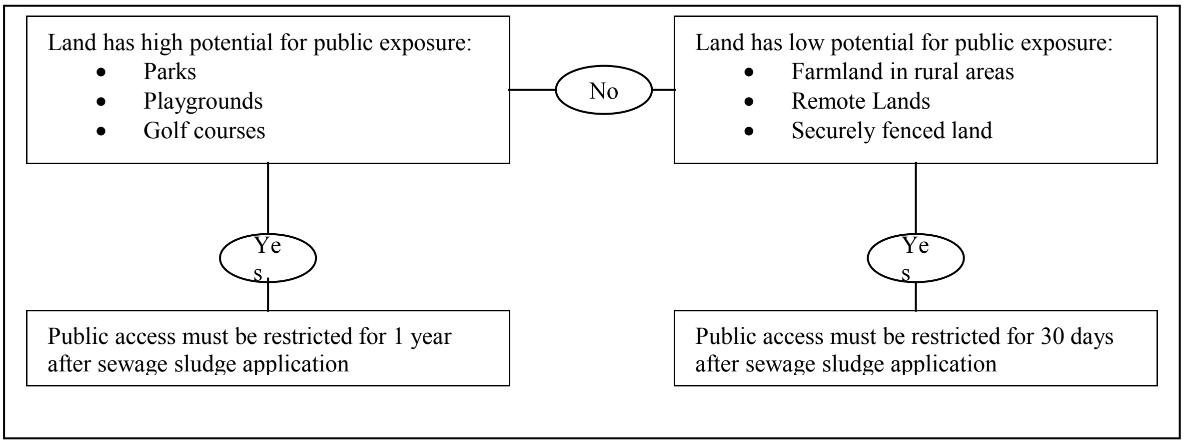

Table 5: Public Access Restrictions for Land Application [12]

In addition to public access control, several other site restrictions may apply, depending on the uses of the land application site. For example, if food crops are grown at the site, certain waiting periods must be observed prior to harvest. Similarly, waiting periods must be observed for sites where feed and fibre crops, as well as turf, are grown and where animals are grazed [12].

3.4 Landfill as a Waste Disposal Method:

Landfill is the most common method of waste disposal throughout the world and involves dumping waste in unused or unwanted sites such as disused quarries or dry mining pits. If the site is well run and adequately funded it can be a safe and relatively inexpensive method of disposal. These landfills have replaced traditional dumps as they are seen as more sanitary (the waste is deposited in a depression and is then compacted and covered with soil). Traditional dumps are open and cause visual pollution, as well as producing an odour and perhaps encouraging pests and in the extreme, disease.

There are three types of landfill, and they depend on type of material that is to be disposed of;

1. **Mono-disposal sites** – Only one specific type of waste is disposed here, usually by industries that produce large quantities of one type of waste.

2. **Multi-disposal sites** – Many different types of waste are disposed of in these sites, usually coming from households, commercial and general industrial firms.

3. **Co-disposal sites**– These sites use chemical, biological and physical processes to break waste down in controlled landfill sites. These sites are generally used for the disposal of special and non-biodegradable waste materials which could be harmful to the environment (physical and human).

Although Landfill is the most widely used method of waste disposal (due to its cost effectiveness) it is still a controversial form of disposal. If landfill sites are not managed properly they can produce harmful pollutants, called leachates, into the groundwater as well as gas emissions. When the site is at its capacity care should be taken to ensure that it is properly infilled, landscaped and monitored for any possible impacts that it may have on the environment [21].

When sewage sludge is to be landfilled, its volume needs to be reduced as much as possible. To accomplish this, the sludge must be dewatered, dried, incinerated or undergo wet oxidation. Dewatering avoids the additional of a large amount of water into the landfill body and also reduces adhesion of sludge to the tires of transport vehicles and compactors. Thermal drying can increase the dry solids content by up to 90%. This reduces transportation costs and effectively meets dumping requirements. The dried sludge needs to be palletized before being dumped, to avoid dusting. Once the pellets are dumped, there is a delay before they take up water from the landfill. When they are moist enough, the pellets will become involved in the microbiological process of the landfill body and leachability will increase with time [23].

Co-disposal of domestic waste and sewage sludge increases the stabilization of the wastes. The reduction of degradable organic compounds leached from the waste is then more rapid and eventually, the quality of the leachate improves. On average, it has been found that the concentrations of heavy metals in leachate from landfills without sludge are higher than in leachate from landfill sites used for co-disposal. This finding was unexpected, as the total metal content in the co-disposal landfill site is greater than in the landfill without sludge. This condition can likely be attributed to the lower pH of the moisture in the landfill without sludge. Landfill costs continue to increase as regulations have been tightening, in part due to the frequent public opposition to the siting of new landfills. Landfill operators demand higher solids content and suitable shear stress characteristics as conditions for tipping. These requirements have an impact on the sludge conditioning technology where sludge is disposal of in landfills [23].

Landfill is by far the largest route for the disposal of waste in the UK. Below figure shows the proportion of different wastes landfilled in the UK. About 120 millions tones of controlled waste per year are landfilled in the UK, which includes 90% of household waste, 85% of commercial waste, 63% of construction and demolition waste and 73% of other industrial waste. Sewage sludge also has a proportion disposed of via landfill, representing about 10% of the total arisings of wet sludge (4% solid content), equivalent to 3.5 million tonnes per year [19].

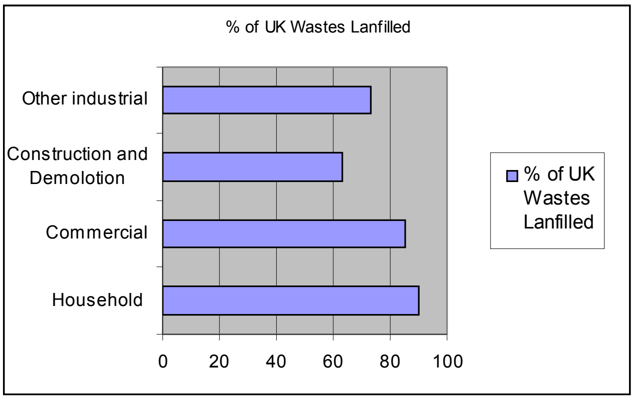

Table 6: Proportion of UK Waste Landfilled (19)

The most common disposal methods, particularly in the UK, are landfill and to a lesser extent incineration. Some waste from sewage sludge is placed in landfill sites, along with waste from mining and quarrying. There are over 4000 landfill sites in the UK. As landfill waste decomposes, methane is released in considerable quantities. Currently it is estimated that over 1.5 million tonnes of methane are released by landfill sites in the UK each year. Methane is a strong greenhouse gas and contributes to global warming. Furthermore, the leachate fluids formed from decomposing waste can permeate through the underlying and surrounding geological strata, polluting groundwater which may be used for drinking water supplies. Containment landfills however, can limit the spread of this waste leachate [19].

In a modern landfill, refuse is spread thin, compacted layers covered by a layer of clean earth. Pollution of surface water and groundwater is minimized by lining and contouring the fill, compacting and planting the uppermost cover layer, diverting drainage, and selecting proper soil in sites not subject to flooding or high groundwater levels. The best soil for a landfill is clay because clay is less permeable than other types of soil. Materials disposed of in a landfill can be further secured from leakage by solidifying them in materials such as cement, fly ash from power plants, asphalt, or organic polymers [22].

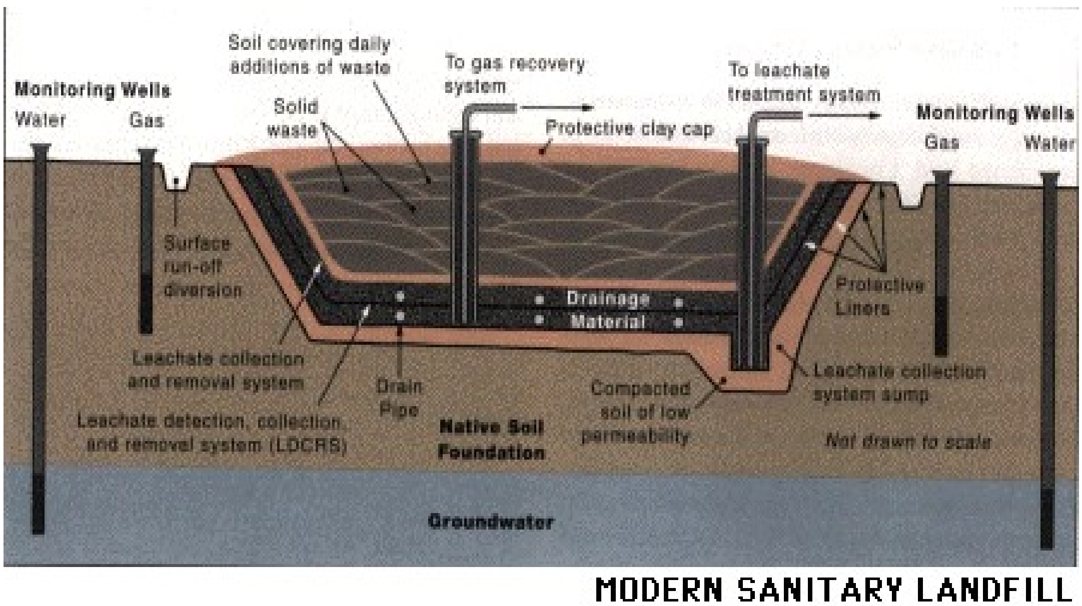

Figure 8: Modern Sanitary Landfill [22]

3.4.1 Site selection and Assessment:

The selection of a site for a waste landfill depends on a wide range of criteria, including the proximity of the site to the source of waste generation, suitability of access roads, the impact on the local environment of site operations, and the geological and hydro geological stability of the site. Site assessment is linked to the information requirement of various bodies involved in the planning, development and operation of the site.

The main aim of the landfill site assessment investigation is the identification of the possible pathways and the receptors of landfill gas and leachate in the surroundings environment and the environment impact of site operations. Site assessment involves appraisal of geological and hydro geological conditions at the site. This may include the use of existing surveys, aerial photography, boreholes, geophysical investigations, geological mapping and sampling etc. The information allows an assessment of soil and bedrock grain sizes, mineralogy and permeabilities, and ground water levels. In addition, the previous use of the site, meteorological data, transport infra-structure and planning use designations, and the planning strategy of the area would also be assessed. A topographical survey is undertaken to calculate the available void space and therefore the waste capacity of the site. Since daily, intermediate and final covering material will be required extensively in the operation of the site, the availability of these materials in natural form should be assessed. At an early stage background levels of water and air quality may be taken to assess the impact of the site in the long term.

For large landfill sites an environmental assessment is also required under the Town and Country Planning Regulations. Environmental assessment involves a description and assessment of the direct and indirect effects of the project on human beings, fauna, flora, soil, water, air, climate and landscape, material assets and the cultural heritage [19].

3.4.2 Landfill design and Engineering:

Landfill disposal is seen in many respects as the bottom rung of the hierarchy of waste disposal options when considering the concept of sustainable waste management. However, the modern landfill site has developed from a site used merely for dumping waste with little or no thought, to a site which is an advance treatment and disposal option designed and managed as an engineering project. The development of the engineered landfill site came about through a series of legislative measures throughout the 1970s and 1980s. The 1974 Control of Pollution Act introduced daily and final covering of the landfill to prevent the problems of litter, accidental fires and arson, flies, vermin, scavenging birds etc. In addition, there was a trend to move to larger well managed landfill sites rather than local sites as a result of the changes in local government organization which moved management responsibility of waste from local to regional control [19].

3.4.3 Considerations for Landfills:

A waste landfill is a major design and engineering project and there are a number of points to be considered as part of the process [19].

1) ***Final Landform Profile***: The profile of the final landform is a key factor in design in that it dictates the after-use of the site, the waste capacity of the site, and settlement of the site after completion and landscaping. Final landform gradient after emplacement of the capping material would normally be between 1 in 4 and 1 in 40, depending on the final use for the site, to ensure adequate safety of the steep slopes and a minimum gradient for suitable drainage. However steep slopes greater than 1 in 10 may require control to offset erosion of the site.

*2) **Site Capacity***:- The Capacity of the site is clearly a key factor in site design, and the determination of how much waste can be accommodated in the site depends on waste density, the amount of intermediate and daily cover, the amount of settlement of the waste during the operation of the site, and the thickness of the capping system.

*3) **Settlement***: - Settlement of the waste in the landfill occurs initially due to physical rearrangement of the waste soon after emplacement. As the biological, physical and chemical degradation processes proceed further settlement occurs from overburden pressure due to compaction by its own weight. Typical long term settlement values for municipal solid waste are 15-20% reduction, although values of up to 40% have been reported where there is a high organic content in the waste. Settlement can take place over periods of time up to 50 years, but the major settlement period occurs within the first 5 years of the final emplacement of the waste. Inert wastes, which do not biodegrade significantly and tend to be denser than municipal solid waste, have low settlement values.

4) ***Waste Density***: The density of the waste within the landfill will vary depends on the degree of pre-compaction of the waste before emplacement, the variation in the components within the waste, the progression of biodegradation, the amount of daily and intermediate cover, and the mass of overlying waste. The degree of pre-compaction of the waste influences the amount of waste that can be accepted into the landfill, and also influences to a marked degree the amount of settlement of the landfill. Typical waste densities range from 0.65 to 0.85 tonnes per cubic meter, although different types of waste may reach densities as low as 0.4 tonnes per cubic meter or up to 1.23 tonnes per cubic meter depending on the amount of biodegradable and inert waste present. Inert wastes have higher densities, typically about 1.5 tonnes per cubic meter [19].

5) Material Requirements: The containment landfill requires various materials for site development, operation and restoration. Included in these requirements are the natural fill materials such as clay, sand, gravel and soil, which are used in various applications such as sand for lining the site to protect the liner materials, clay to provide an additional low permeability layer to the site, gravel for drainage for leachate collection, clay for capping material and restoration soils. The availability of such materials on site increases the ease of operation and also reduces costs.

6) Drainage: Drainage of the rain water falling on the site is required to ensure that excessive water does not infiltrate the waste directly or from run-off from surrounding areas. Cut-off drains both around and inside the site will keep the waste from becoming too wet and increasing the production of leachate [19].

3.4.4 Types of Waste Landfilled:

All landfill sites in the UK require a license to operate, and these are issued by the Environment Agency. The licensing of waste disposal on land was introduced in the Environment Protection Act 1990 and the licensing system set out in the waste Management and Licensing Regulations 1994. For large facilities an Environmental Assessment may be required to obtain planning permission. The waste management license includes details of the types and quantities of waste which are permitted to be handled at the site [19]. Three categories of waste have been defined, and each landfill site license applies only for the categories listed there on:

1. Inert Wastes: This is that wastes which will not chemically react decompose by biodegradation or leach pollutants into the environment, and which therefore do not pose an environment risk either now or in the future. Inert wastes, as their name suggests, are waste of no or low reactivity, i.e. they do not undergo major chemical, biological or physical degradation to yield polluting materials. For example, certain construction materials and incinerator bottom ashes are classified as inert. Consequently, only passive control systems are required.
Inert wastes are disposed of in ease and scatter type of site provided that they are totally inert and unreactive. They may also be disposed of in the higher level type of landfill, the containment landfill.

2. Bioreactive Wastes: This is that wastes which undergo biodegradation within the landfill environment. Municipal solid waste is an example of Bioreactive waste. Biodegradation involves detoxification in order to stabilize the landfill. Stabilisation refers to the degradation of organic matter in the waste to stable products and the settlement of the material in the site to its final rest level. Bioreactive wastes are disposed of in containment landfills where a barrier system of liner materials contains the leachate and landfill gas generated.

3. Hazardous/industrial or Special Waste: This is that wastes which may be acceptable at co-disposal sites where co-disposal is with biodegradable wastes such as municipal solid waste. The biodegradable waste aids the decomposition of the hazardous waste. The hazardous, industrial or special waste may be solid, sludge or liquid material. Hazardous /industrial or special wastes are co-disposed in containment-type landfills with a high specification liner system to contain the derived leachate and landfill gas [19].

4. RESULTS AND DISCUSSIONS:

4.1 METHOD AND LOCATION OF SURVEY:

A case study method for survey was carried at Cumnock Sludge treatment centre (Scottish water) located in Ayrshire Scotland and Cathkin near to Carmunnock Village in South Lanarkshire. Cumnock Waste Water Treatment Plant is a centre for sludge treatments and Cathkin is an operational landfill site. Sludge gets treated with the process of Anaerobic Digestion.

4.2 METHOD OF SLUDGE TREATMENT AT SCOTTISH WATER TREATMENT PLANT

Sludge import @ 2%-3% dry solids is received from the existing works and from import tankers and is discharged into the imported sludge reception tank Sludge is screened to 6mm and is then passed to the belt thickeners, using a polyelectrolyte dosing system, where it is thickened to 6% dry solids. The thickened sludge enters the sludge buffer storage tank and is stored within the tank on an 8 hours per day for 5 days basis whilst allowing the digester feed pump to operate over a 24 hours per day for 7 days basis.

The sludge is then pumped to the digesters, which are heated to 35°C ± 3°C for a period of 12-24 days. The temperature is maintained by circulating sludge through temperature controlled heat exchangers and returning it to the digesters. A proportion of gas is drawn from the gas holder and returned to the digesters via diffusers to ensure thorough mixing of the sludge.

The CHP and boiler units are normally fuelled on biogas but also have the facility to burn natural gas. The natural gas supply to the boiler and CHP units is taken directly from the main supply. Any excess gas from the gas holder passes to the waste gas flare stack and is automatically burned off.

The sludge enters the digested sludge collection sumps and is transferred to the digested sludge storage tanks where it is stored for up to 4 months, allowing to cool and settle. The liquid, @ 4% dry solids is manually consolidated and decanted to 6% dry solids before it is exported. If sludge cake is required, as determined by the operator, the sludge will be returned via the digested sludge storage tank outlet valves to the digested sludge collection sumps. The sludge is then pumped to the centrifuges.

Polyelectrolyte solution is dosed into the digested sludge at the inlet to the centrifuges to aid thickening up to 28 ± 3% dry solids. The resultant sludge cake is deposited onto a screw conveyor for removal to a cake storage area where it is stored for up to 6 months before being transported away via a weighbridge.

Sludge liquors from various sources are passed to the liquors treatment plant. The liquors collection and balance tank operates on a 24 hour, 7 day basis whilst allowing the belt thickeners and centrifuges to operate on an 8 hour, 5 day basis. Three batches of liquor per day enter the reactor for the sequential operation of the batch reactor. The effluent flows to the final effluent balancing tank for collection and buffering for the booster pumps and then into a chamber provided with flow measurement to the river at a controlled rate. The effluent flows to the river at a rate of 4 liters/second @ 30/20/10 mg.

Final effluent is drawn from the balancing tank and is distributed to various process areas by the final effluent washwater pumps. Portable water is received in the washwater break tank and is distributed to hose points and process equipment by the portable washwater pumps. The odour control system has a biofilter unit which treats malodorous air generated by the treatment processes in various units.

4.2.1 Process Description of Waste Water Sludge Treatment

4.2.1.1 Sludge Screening

Sludge is received by the sludge screens from the imported sludge transfer pumps. The screens operate on a duty/standby basis with automatic changeover from duty to standby on failure of the duty screen.

Figure 9: Imported Sludge Holding Tank

4.2.1.2 Sludge Thickening

Sludge received in the screened sludge sump is maintained in a homogeneous state by operation of the submersible mixer. Sludge is transferred to the belt thickener plant by the thickener feed pumps. The belt thickener plant operates as duty/standby streams with a feed pump, thickener unit and polyelectrolyte dosing pump operating as a dedicated stream. The system is to be configured so that automatic changeover from duty to standby stream occurs on failure of the duty stream.

a) Belt Thickeners

Sludge is transferred to the belt thickener plant by the thickener feed pumps. Each belt thickener operates as a stream together with a feed pump and a poly electrolyte dosing pump. Control of the thickener unit, associated feed pump and polyelectrolyte dosing pump is to be via the main PLC. The duty stream is to be manually initiated by the plant operator at the start of each shift.

Figure 10: **Belt Thickener**

b) Thickener Polymer Plant

The Tomal SV 4, 0 is a turnkey, automatic machine for batch preparation of polymer solutions. A powder feeder starts and polymer powder is fed into the dissolver cone. An ejector sucks down, mixes and transports the solution into the preparation tank. The solution is kept in motion and once matured, is transferred to the stock tank. The stock solution is pumped from the stock tank to the dosing points.

Controls of the polyelectrolyte dosing pumps are via the main PLC and are called to run in conjunction with operation of the respective thickener stream. The poly make up is controlled by a separate hardwired control panel supplied by the poly plant manufacturer.

4.2.1.3 Primary Digesters:-

a) Digester No. 1 Sludge Circulation

Digesting sludge is to be circulated from digester no. 1, through digester no. 1 to heat exchanger and back to digester no. 1 by digester no. 1 sludge circulation pumps. The pumps are to operate in duty /standby mode with automatic changeover from duty to standby pump on failure of the duty pump. Duty pump is to run constantly.

Figure 11: Digester No 1

b) Digester No. 2 Sludge Circulation

Digesting sludge is to be circulated from digester no. 2, through digester no.2 to heat exchanger and back to digester no. 2 by digester no. 2 sludge circulation pumps. The pumps are to operate in duty /standby mode with automatic changeover from duty to standby pump on failure of the duty pump. Duty pump is to run constantly.

The sludge is drained down and refilled in digester tanks in the following Sequence:

Drain Down

i. Gradually run down the digester to be taken out of service and ramp up other digester to compensate over a period of 7 days.
ii. Shut of associated feed pumps and isolate
iii. Turn off heating system and allow digester to cool for 7 days
iv. Isolate gas mixing compressor and gas draw off.
v. Purge digester with nitrogen

vi. Draw down digester to collection sump. This requires careful monitoring and control because the digester volume is greater than that of the collection sump.

vii. Vent digester via access manways.

Filling

i. Refill using previously digested sludge (seed sludge) to make seals

ii. Purge digester with nitrogen

4.2.1.4 Heat Exchanger, CHP Unit/Boiler Water Circulation

Hot water is to be circulated around the heat exchangers, CHP Unit and Boiler circuits by the heat exchanger water circulation pumps. The duty circulation pump is to run constantly. Each heat exchange is to be provided with a three way diverter valve controlled from the main PLC to maintain heat exchanger sludge outlet at the desired temperature and to provide control of the temperature of the sludge balance tank liquors.

Figure 12: Heat Exchanger

4.2.1.5 CHP Unit:

The CHP unit is to operate on sludge gas when available and on natural gas when sludge gas is not available. Thermal energy provided by the CHP unit will be exchanged to the primary recirculation water from the heat exchanger water circulation pumps, by a heat exchanger supplied as part of the CHP unit by the CHP unit suppliers.

A hardwired signal will be taken from the gas holder level sensor to the CHP control system which will control the gas supply to the CHP unit. When the level in the gas holder reaches the pre-set high level, the CHP unit will automatically changeover to natural gas. When the gas holder level returns to a pre-set high level, the CHP unit will automatically change back to sludge gas. The changeover from sludge gas to natural gas and back again is to be achieved by the gas trains and associated valves supplied by the CHP unit and are to be controlled from the local control panel supplied as part of the CHP unit package.

To operate in the part- load mode, the CHP unit suppliers control panel will allow the operator to manually input the desired part-load for set periods of time against a real time clock. The CHP unit will then be controlled by the level in the gas holder as described above for full load.

4.2.1.6 Boiler

The Boiler has two functions:-

1) As a standby unit for the CHP unit
2) To provide additional heat for the digesters and liquors treatment plant in cold weather periods.

The boiler will be installed in series with the CHP units. In normal operation, thermal energy will be supplied to the primary recirculation water by the CHP unit. The boiler will be constantly maintained at a pre-set temperature, controlled by internal functions of the boiler unit. While the CHP unit is running, this will be maintained on low fire pilot flame.

In the event of the CHP unit not providing sufficient heat to the recirculation water (such as maximum heat demand from the digesters and heat exchangers in cold weather), the boiler will automatically operate to maintain the outlet temperature of the water from the boiler to a pre-set value. If the CHP unit is showing a duty signal to the

PLC but the boiler is required, an alarm will be raised via SCADA, and the boiler will start up on bio gas providing there is an adequate supply of bio gas detected by the level in the gas holder.

The boiler is to operate normally on sludge gas. A hardwired signal will be taken from the Gas Holder level sensor to the boiler control panel which will control the gas supply to the boiler unit. When the level in the gas holder reaches a pre-set high level, the boiler unit will automatically operate on sludge gas. When the level in the gas holder falls to a pre-set low level, the boiler unit will automatically changeover to natural gas. When the Gas Holder level returns to a pre-set high level, the boiler unit will automatically change back to sludge gas. The changeover from sludge gas to natural and back again is to be achieved by the gas trains and associated valves supplied by the boiler unit and are to be controlled from the local control panel supplied as part of the boiler package.

The inlet temperature to the boiler should not fall below 60 degrees C to prevent corrosion in the boiler. Therefore the boiler will be supplied (as part of the boiler package) with a recycle 'shunt' pump to maintain the inlet temperature above 60 degrees C.

4.2.1.7 Heat Dump Radiator

The heat dump radiator is to maintain a constant water temperature in the CHP Unit/Boiler primary water circuit to enable the CHP Unit to operate when either or both of the digester do not require heat.

The heat dump radiator will contain 2 variable speed drives, controlled by the outlet water temperature and supplied as part of the heat dump radiator package. By varying the speed to control the temperature the fans can run continuously giving a narrower temperature band.

4.2.1.8 Gas Holder

The gas holder is to be of the flexible membrane type with the gas pressure in the inner being maintained by pressurizing the space between the inner and outer membranes with air. The air is to be supplied by duty/standby air blowers and the quantity of gas in the inner membrane is to be sensed by an ultrasonic level detector.

4.2.1.9 Excess gas Burner Flare

The excess gas burner flare is to burn all excess gas produced by the digestion process. A low level burner has been provided for the disposal of excess gas that the digestion process normally produces. Any excess gas from the gas holder passes to the waste gas flare stack and is automatically burned off. The flare stack is initiated on a high level in the gas holder and continues to burn until a low level is reached. Failure of the flare stack raises an alarm at the SCADA workstation and via telemetry.

Figure 13: Flare Stack

Gas entry into the flare system is via an isolation valve, whilst the operational flow of gas to the burner heads is controlled by a motorised valve. Gas passes down the main line to the burner manifold where it divides into five burner heads for flaring inside the combustion chamber. The combustion chamber is open at the top and raised off the ground to allow air to be entrained for complete combustion of the gases. The open section at the bottom of the chamber is surrounded with a detachable mesh chamber guard for protection of plant personnel whilst still allowing air into the chamber for a good air/gas mix.

Gas for the pilot line is taken from the main line at a point before the motorised valve to ensure a gas supply for the pilot. Gas to the pilot tip is governed by a solenoid valve fitted in the pilot line, and the correct air/gas mix is achieved via a pilot air injector. Similarly, gas to the igniter line is also governed by a solenoid valve, and the correct air/gas mix for ignition is achieved via an igniter air injector. To prevent a 'flashback' from passing through the flare system, one flame arrestor is fitted into the gas line and is situated between the main line and the burner manifold.

4.2.1.10 Mixing Compressors

a) Digester No.1 Mixing Compressors

Sludge gas is to be drawn from Digester No. 1 gas off take line and delivered to 9 off mixing lines in Digester No. 1 by Digester No. 1 Mixing Compressors.

b) Digester No.2 Mixing Compressors

Sludge gas is to be drawn from Digester No. 2 gas off take line and delivered to 9 off mixing lines in Digester No. 2 by Digester No. 2 Mixing Compressors.

4.2.1.11 Gas Boosters

Sludge gas is to be drawn from the gas holder by gas boosters and delivered to the CHP unit and boiler. The booster set is located in the boiler room and is provided to ensure that the inlet gas pressure at the CHP unit is maintained at the desired level.

The duty booster is to be run if either the CHP unit is run on sludge gas or the boiler is run on sludge gas. The duty booster pump is initiated by the CHP being called to run on sludge gas, or the CHP switching over to sludge gas or the boiler being initiated on sludge gas. The delivery pressure to the CHP/boiler units is monitored by a pressure switch, located on the common discharge line. If the duty pump has been running for a preset time and the pressure switch is not measuring above low pressure, the duty drive fails and the standby drive is called to run.

4.2.1.12 Building gas and Smoke Detection

The boiler room is to be provided with a gas and smoke detector which is to be linked to automatic isolation valves in the sludge gas and natural gas feed lines to the building. The valves are to be normally open solenoid valves which will close if smoke or high gas levels are detected in the boiler room.(The above valves are to be battery backed to allow correct operation if the plant suffers from a power failure).

4.2.1.13 Gas Flare Unit

The excess gas burner is to burn all excess gas produced by the digestion process. The operation of the burner is to be controlled from a local control panel which is to be supplied as part of the excess gas burner package. Control of burner local control panel will be monitored by the main PLC. Burner is to be initiated when a high level set point is reached in the gas holder.

4.2.1.14 Dewatering System (Centrifuges)

The Dewatering system consists of two streams consisting of the following equipment for each stream:

- Duty/Standby feed pumps
- Polyelectrolyte dose pump
- Centrifuge (consisting of a screw feed and centrifuge drive)
- Conveyor system

Common to both streams is the following equipment:

- Polyelectrolyte make up system
- 2 off screw conveyors to transfer dried sludge to the cake reception area.

a) Sludge Dewatering Plant

Sludge is transferred to the centrifuge dewatering plant by the centrifuge feed pumps with a duty/standby set of feed pumps dedicated to each centrifuge. The centrifuge dewatering plant is to operate as duty/duty streams with a duty/standby feed pump, centrifuge and polyelectrolyte dosing pump operating as a dedicated stream.

Figure 14: Digested Sludge Storage Tank

b) Sludge Cake Conveyors

Sludge cake produced by the centrifuges is to be transferred by a horizontal and inclined conveyor to a cake reception area from where it is to be transferred manually to the cake storage area. Sludge cake discharged from either centrifuge falls onto a horizontal, inclined screw conveyor. This deposits the cake at a cake reception area.

An actuated slide valve opens to deposit the cake onto the conveyor from centrifuge n°1. The conveyor passes through the building wall to discharge the cake into a pile of approx. 1.5m high adjacent to the building. The cake is then transferred manually to the cake storage area using a front loading shovel vehicle.

4.2.1.15 Poly Plant Stock Level

The Tomal SV 4, o is a turnkey, automatic machine for batch preparation of polymer solutions. A powder feeder starts and polymer powder is fed into the dissolver cone. An ejector sucks down, mixes and transports the solution into the preparation tank. The solution is kept in motion and once matured, is transferred to the stock tank. The stock solution is pumped from the stock tank to the dosing points.

Low level will inhibit operation of both polyelectrolyte dose pumps and inhibit operation of both dewatering streams. An alarm will be raised at the SCADA workstation low inhibits. The inhibit condition will be removed when the level has returned above the low inhibit level for a continuous period of 5 minutes (adjustable at SCADA).

4.2.1.16 Sludge Liquors Collection and Balancing

The purpose of the sludge liquors collection and balance tank is to allow operation of the main liquors producing equipment (belt thickeners and centrifuges) on a 5 day per week, 8 hours per day basis whilst allowing the liquors treatment process to operate on a 7 day per week, 24 hour per day basis. The liquors are heated to provide the optimum process conditions necessary for treatment. This is achieved by circulating sludge through a temperature controlled heat exchanger and returning it to the balance tank.

The tank collects liquors from the following sources and buffers the flow prior to feeding to the liquors treatment reactor:

1. Belt Thickeners
2. Gas holder condensate trap chamber
3. Digested Sludge storage tanks
4. Dewatering equipment
5. Cake storage area
6. Sodium hydroxide delivery area drainage
7. Biofilter unit
8. Poly Prep units

Figure 15: Storage Liquors Collection and Balancing Tank

The tank is provided with two mixers which are both duty units. The purpose of the mixers is to maintain a homogeneous blend of liquors in the tank as required by the liquors treatment reactor.

4.2.1.17 Sludge Liquors Treatment Plant Feed

Liquors received in the sludge liquors collection and balance tank are to be transferred to the liquors treatment reactor by the sludge liquors treatment plant feed pumps. Pumps are to operate in duty/standby mode with automatic changeover from duty to standby pump on failure of the duty pump.

4.2.1.18 Sludge Liquors Treatment Heat Exchanger

Sludge liquors received in the sludge liquors collection and balance tank can be heated via the liquors heat exchanger. The control valves control flow to the liquors reactor or to the heat exchanger.

4.2.1.19 Sludge Liquors Treatment

a) Liquors Treatment Reactor:-

The liquors treatment reactor is to be a sequencing batch reactor which is to operate such that treatment of the liquors is carried out in separate stages with the duration of each stage being controlled by a timer in the PLC.

b) Sequencing Batch Reactor (SBR)

A Sequencing Batch Reactor (SBR) is used as the liquors treatment reactor. This is a fill and draw activated sludge system and as such the unit processes involved in a SBR and a conventional activated sludge system are identical. The important difference however is that in a conventional system the processes are carried out simultaneously whereas in SBR operation the processes are carried out sequentially in the same reactor. The individual steps undertaken in the operation of an SBR are detailed below:-

STAGES	OPERATION
Fill	In this operation wastewater/return liquor is fed to the reactor to provide substrate. The extent of liquor entering the reactor is controlled either on time with level back-up or on level alone.
React	The purpose of the react stage is to complete the reactions that were initiated during fill.
Settle	This stage allows solids separation to occur, providing a clarified supernatant to be discharged as effluent.
Draw	The purpose of the draw stage is to remove clarified water from the reactor. A decanting arm is used.

Table 7: Sequencing Batch Reactor

Liquors received in the Liquors Treatment Reactor are to be maintained in a homogeneous state during the Feed and Denitrification stage by operation of the submersible mixer. The mixer is to operate constantly during the timed Feed and Denitrification stage, initiated by the main PLC. However operation of the mixer is inhibited at the end of the pre-set timed Feed and Denitrification stage and is also inhibited should a low level be detected within the reactor itself.

Air is drawn from the atmosphere and delivered to a set of flexible membrane diffusers in the Liquors Treatment Reactor by the Liquors Treatment Air Blowers. The blowers operate on a duty/standby mode with automatic changeover from duty to standby blower on failure of the duty blower.

The blowers are variable speed positive displacement machines and are provided with an electrically controlled unloading valve to allow start up of the duty blower on line. The valve is to open on start up of the blower until the unit has reached full output and is then to close to allow air to flow to the diffusers.

During the nitrification and BOD removal stage of the cycle, the speed of the duty blower will be controlled directly from the two Dissolved Oxygen probes in the Liquors Treatment Reactor to maintain a dissolved oxygen level of 2.0mg/l.

c) Liquors Treatment Reactor Aeration

Air is drawn from atmosphere and delivered to a set of flexible membrane diffusers in the liquors treatment reactor by the liquors treatment air blowers. The blowers are positive displacement type and are provided with an electrically controlled unloading valve to allow start up of the duty blower on line. The valve is to open on start up of the blower until the unit has reached full output and is then to close to allow air to flow to the diffusers.

d) Liquors Treatment Reactor Mixer

Liquors received in the liquors treatment reactor are to be maintained in a homogeneous state during the Feed and Denitrification stage by operation of the submersible mixer.

4.2.1.20 Sodium Hydroxide Storage Tank

Sodium hydroxide is to be stored in a bulk storage tank and maintained at 20 deg C in the sodium hydroxide storage tank. One sodium hydroxide storage tank is required for pH correction for the Liquors Treatment Reactor. Due to the freezing point of 47%w/w sodium hydroxide, the storage tank requires heating to approximately 25 °C and the pipe work trace heated. The electric heater will be directly thermostat controlled by the heater integral control system. The trace heating tape is to be of the self regulating type.

4.2.1.21 Sodium Hydroxide Dosing Pumps

The dosing pumps dose the hydroxide into the liquors treatment reactor during the aeration phase.

a) Sodium Hydroxide Dosing:

The pH of liquors received in the liquors treatment reactor is to be maintained at a value of approximately 7.5ph by dosing of sodium hydroxide dosing pumps. The pH set point can be varied via SCADA. The Sodium Hydroxide Dosing Pumps operate on a duty/standby mode with automatic change over from the duty to the standby pump on failure of the duty pump.

Figure 16: Sodium Hydroxide Dosing Pump

4.2.1.22 Final Effluent Balancing Tank

This is for collection and buffering of final effluent for final effluent booster pumps. Effluent from the Sequencing Batch Reactor flows into the final effluent balancing tank, for collection and supply for final effluent booster pumps. An ultrasonic level measuring transmitter is provided in the tank. If high level is detected, decanting of the SBR will be inhibited and an alarm will be raised at the SCADA Workstation.

4.2.1.23 Works outfall Flow Measurement Chamber

Flow measurement and flow control of final effluent to the river. The chamber is provided for flow measurement and control of the final effluent to the river via a V-notch weir. The chamber is equipped with an ultrasonic level instrument. If a high flow rate is detected an alarm will be raised at the SCADA Workstation. The inlet to works outfall flow measurement valve is controlled via the PLC to maintain a set flowrate to the river above a pre-set level in the balancing tank. The chamber has a turbidity monitor for colour monitoring.

4.2.1.24 Odour Control

The Biofilter of the Odour Control system is to be provided with irrigation water by the effluent washwater pump package system. Control of the irrigation system requirements are to be determined by the suppliers and details given below should be considered as preliminary until the Odour Control System supplier is selected.

The odour control unit consists of the following items:-

i. Peat/Heather bed filter housing
ii. Filter Bed Sprinkler System
iii. Filter Material
iv. Dehumidifier
v. Dry Scrubber Unit
vi. Process Exhaust Fans

a) Odour Control system

The Odour Control System is to incorporate a BIOFILTER for treatment of the relatively low volume, high concentration air from the sumps and process units and a activated carbon filter for the treatment of the relatively high volume, low concentration air from the Process Building. The design of the Odour Control System is preliminary only and is to be adjusted when the actual supplier is selected. The control requirements detailed below should therefore be considered as preliminary only.

The odour unit is to be provided with dedicated duty/standby fans with automatic changeover from duty to standby fan on failure of the duty fan. It should be noted that the ventilation of sumps, process equipment and the Process Building by the Odour Control System fans is an important safety function. Ventilation of these areas is designed to prevent the build up of toxic and flammable gases and is therefore critical to the safe operation of the plant.

In the event of complete power failure to the plant there is the possibility of a build up of toxic and flammable gases as sufficient ventilation will not occur when the fans are not available. In order to prevent any potential hazards when the power is restored the Odour Control System fans are to start up and operate for a period of at least 30 minutes before any other electrical equipment is initiated.

The Odour Control System incorporated a Biofilter Unit which treats malodorous air generated by the treatment process in the following units:

1. Screened/Thickened Sludge Buffer Tanks No.1 and No.2 - High Odour
2. Screened Sludge Sump - High Odour
3. Sludge Liquors Collection and Balancing Tank - High Odour
4. Imported Sludge Reception Tank - High Odour
5. Centrifuges Nos.1 & 2 - High Odour
6. Belt Thickeners Nos.1 & 2 - High Odour
7. Screens Nos. 1 & 2 - High Odour
8. Tank Corridor - Low Odour
9. Pump Gallery - Low Odour

4.2.1.25 Portable Washwater System

Portable Water is received in the washwater Break Tank and is distributed to the hose points and process equipment by Portable Washwater Pumps. The pumps are to operate in duty/assist/standby mode with automatic initiation of the assist pump and automatic changeover from duty/assist pump to standby on failure of the duty/assist pump.

a) Potable Washwater Distribution System

The washwater pumps draw potable water from the break tank and distribute it to the following areas:

i. Hose Points within Main Building
ii. Sludge Screens
iii. Centrifuge Polymer Preparation Plant
iv. Centrifuge Package
v. Belt Thickener Polymer Preparation Plant

vi. Heating System Header Tank
vii. Emergency Shower
viii. Belt Thickener Package
ix. Hose Points on Site Ring Main

4.2.1.26 Final Effluent Washwater System

Final effluent is taken from the final effluent balance tank and distributed to the various process areas by Washwater pumps. The pumps are to operate in duty/standby mode with automatic initiation of the assist pump and automatic changeover from duty/assist pump to standby on failure of the duty/assist pump.

4.3 A COMPARISON BETWEEN ANAEROBIC, AEROBIC AND LANDFILL METHODS ON THE BASIS OF TREATMENT PROCESS:

The comparison between the anaerobic, aerobic and landfill methods were done on the basis of the survey carried and the data was compared on the basis of calorific value, process time, labour, operating cost, capital cost, odour etc. to find out the most efficient sludge disposal method.

4.3.1 Calorific Value Comparison of the Anaerobic, Aerobic and Landfill Methods

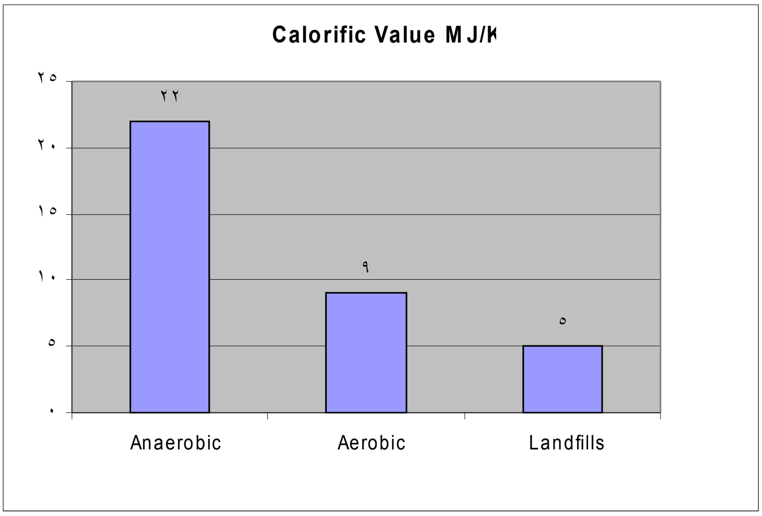

Table 8: Calorific Value Graph [24]

The calorific value comparison was done between the anaerobic, aerobic and landfill methods. In the case of anaerobic digestion, the calorific value is higher i.e. 22 MJ/KG than the other two aerobic and landfill technology i.e. 9 MJ/KG and 5 MJ/KG. The higher the calorific value, the high amount of methane gas is produced. On the basis of good amount of methane production, anaerobic digestion method is considered to be the best in case of calorific value.

4.3.2 Comparison of Anaerobic, aerobic and landfill method on the basis of different Sludge Disposal Methods [25]:

The comparison between anaerobic, aerobic and landfill methods were done on the basis of different sludge disposal methods, by comparing the various criteria's used in sludge disposal methods as these factors plays a important role in the outcome of final disposal.

Criteria	**Anaerobic Digestion**	**Aerobic Digestion**	**LAndfills**
Labour	**Low**	High	Medium
Capital Cost	**High**	Medium	Low
Operating Cost	**Low**	High	medium
Process Time	**3 weeks Digestion, plus 5 weeks composting**	12 weeks	-
Space requirement	**50%**	100%	100%
Odours	**20%**	75%	100%
Energy Balance	**Energy Surplus**	Energy Demand	Less Energy
Biogas Production	**100-150 m3/Mg**	Nil	200-400 m3/tonne
Sludge production	**Low**	High	N/A
Energy Cost	**Low**	High	Medium
Reactor Volume	Small	Large	**No need**
Application	**Digestate**	Compost	Direct to land
BOD Reduction	**Higher**	Medium	Very Low
Reliability	**Improved**	Medium	Less

Table 9: Comparison of Anaerobic, Aerobic and Landfill Methods

On the basis of labour required for the three different methods i.e. anaerobic, aerobic and landfill, the data showed that labour required for anaerobic was less as compared to aerobic and landfill methods, as in their case the labour requirement is higher.
Taking the second criteria of capital cost, which is an important criterion. In this case aerobic and landfill method showed medium to low capital cost as compared to anaerobic method, which has shown high capital cost. If the labour required is least in process the capital cost can rise as shown in case of anaerobic method.

In case of operating cost between the three methods, the anaerobic showed low operating cost as compared to the other methods aerobic and landfill, where the operating cost ranged between high to medium.

While comparing the process time of the three methods it was observed that anaerobic digestion methods take 3 weeks of time for digestion and 5 weeks for composting, whereas in the case of aerobic digestion method, the digestion of sludge can take up to 12 weeks or more and for landfill the time is too long. While comparing the process time anaerobic seems to be the best method as time consumed in this process is shorter than the other two processes.

The space requirement for the anaerobic treatment plant is just 50% of the aerobic treatment plant and landfill treatment plant. The space required in aerobic and landfill is just double the anaerobic treatment plant.

The odour produced by anaerobic method is just 20% of the aerobic and landfill method. Whereas in case of aerobic and landfill method the odour percentage reaches up to 75 and 100. With the high percent of odour produced in the process the working atmosphere becomes unhealthy and it also pollutes the surrounding areas. It also affects the work efficiency of the people working in that area.

The energy produced in three process vary, as in case of aerobic digestion the additional energy is required to complete the process, for landfill method less energy balance is left, which can increase the cost of process. But in case of aerobic digestion method surplus energy balance is there, which makes the process cheaper than the two.

In case of bio-gas production, anaerobic process produces the 100-150 m3/Mg which is very high and landfill produces the 200-400 m3/tonne which is very low and in aerobic digestion, no bio-gas is produced.

In case of sludge production, the anaerobic method showed less sludge production as compared to aerobic and landfill method. The sludge produced in aerobic was higher than anaerobic method and less than landfill method. As in case of landfill method the sludge produced is maximum as compared to the both technologies.

The energy cost for anaerobic digestion is less as compared to aerobic and landfill method which showed high to medium. As process time consumed in anaerobic method is less, the energy required is less, where as compared to aerobic and landfill method.

There is no reactor volume required for landfill method as compared to anaerobic and aerobic method, where the requirement of reactor volume is from small to large.

The mode of application used on sludge disposal in the three method are different as in case of anaerobic method the application method used is digester, where the sludge is directly digested, whereas in case of aerobic method the mode of application used is composting, where the material is first compost and then digested and lastly in case of landfill method the sludge is directly filled in land for digestion.

In case of BOD, the anaerobic process showed least amount of BOD production i.e. BOD reduction is higher as compared to aerobic process and landfill process, where the BOD reduction medium to very low ass compared to anaerobic process i.e. the BOD produced in these processes is higher as compared to anaerobic process.

Anaerobic process is considered more reliable with improved technology than aerobic process and landfill process. The reliability of aerobic process is medium as compared to anaerobic process but in case of landfill method the reliability is very less as compared to both the processes.

So in the end while comparing the major factors of waste water treatment process between the three technologies i.e. anaerobic, aerobic and landfill, it can be said that anaerobic digestion of sludge proved to be best technology in almost every aspect followed by aerobic technology and landfill technology.

4.3.3 Comparing Cost Effectiveness among the three Technologies:

The cost effectiveness is compared on the basis of cost consumed in £ (pound) per cubic meter of sludge. The comparison for the cost effectiveness was done on this basis. As to treat 1 x m3 of sludge the cost approximately will include screening, transfer, thickening, digestion, dewatering and removal of sludge. As the data was calculated it showed that in case of landfill method cost effectiveness is least as compared to anaerobic digestion of sludge and aerobic digestion of sludge. (The values shown in table are supposed for an example to be shown).

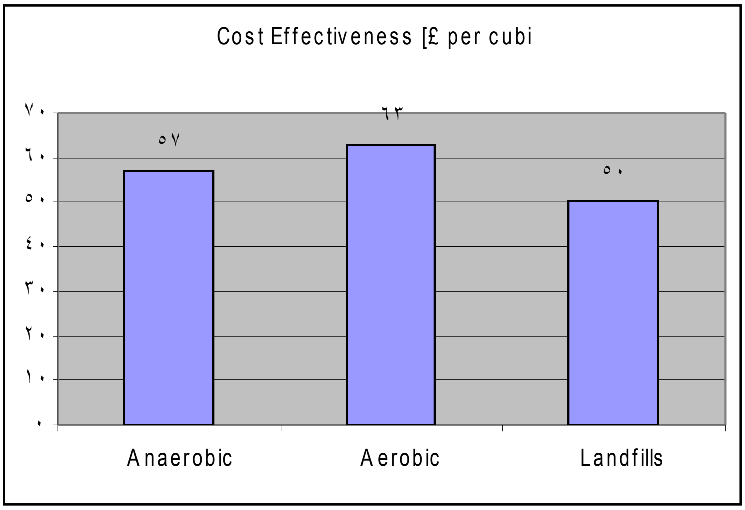

Table 10: Graph of Cost Effectiveness

4.3.3 Comparison of Risk Factors among the Anaerobic, Aerobic and Landfill Technology

There are some risk factors in every technology [27]. By comparing the three technologies it make us easy to find out which technology has least risk factor.

Risk Factors for Anaerobic Digestion:

- Hazards arise from explosion. If the amount of gas increases in the digester, there is a risk to explode the digester.
- There may be some risk to human health with the pathogenic content of feedstock.
- There may also be some risks of fire.
- Destroying of all pathogens does not take place like Prions (e.g. mad cow disease, chronic wasting disease) and thermo resistant bacteria (e.g. Bacillus cereus).
- There is a health risk to farm animals fed on the silage if present in anaerobic digestion residues applied to crops prior to ensilage.

Risk Factors for Aerobic Digestion:

- There is detergent in sludge in aerobic digestion which is very harmful.
- Alkyl Benzyl Sulphonate (ABS) is present in the sludge which is 40% biodegradable.
- Excessive and prolonged inhalation of mists may cause a chronic inflammatory reaction of the lungs and a form of pulmonary fibrosis.

Risk Factors for Landfill:

- Due to releasing of gas from the wastes there may also be risks of fire.
- This waste increases the number of flies and mosquitoes, due to these insects there will be risk of diseases.
- It increases the water pollution.
- It also increases the air pollution.
- There may be risks of leaking of leachate [27].

4.4 HEALTH RELATED ISSUES

There are some health related issues which should be considered. Prolonged and repeated contact with oil products can be detrimental to health. The main hazards arise from skin contact and the inhalation of mists. Skin contact under conditions of poor hygiene and over prolonged periods can lead to defatting of the skin, dermatitis, erythema, oil acne oil folliculitis. Excessive and prolonged inhalation of oil mists may cause a chronic inflammatory reaction of the lungs and a form of pulmonary fibrosis. There are some points related to health issues:

- Harmful by ingestion and contact with open wounds.
- Contact may cause irritation to the eyes and skin.
- May produce poisonous and asphyxiant gases.
- People working with screenings must be advised of the hazards of Leptospirosis (Weil's disease).
- Avoid confined and/or non-ventilated area.
- Avoid confined and/or non-ventilated area.

5. Conclusion and Recommendation:

Aerobic digestion is a valuable process for industrial waste application, when convenience and ease of operation over-shadow any concern for recoverable energy. In such cases, sludge quantities are usually small, making an economical disadvantage with competing process minimal. It is an alternative to anaerobic digestion, involving a simpler process and operation, lower capital costs, and eliminating the potential for releasing odorous or hazardous gaseous by-products. Its disadvantages are higher net energy costs resulting from aeration and mixing power, and not producing recoverable energy (methane). Two significantly criterion limits the viability of aerobic sludge digestion in industrial facilities when employed exclusively for solid reduction. First, because of the relatively small quantities of sludge generated dewatering and/or disposal cost may not be significantly reduced and may not offset the digester capital and operating costs. Secondly, in some cases the dewatering qualities of aerobically digested sludge is poor, requiring enhanced sludge conditioning or increased dewatering capacity, which may offset the potential savings from reduced sludge volumes [28].

Landfill can no longer be considered as one of the best options in terms of disposing of waste. The sheer cost and the risk of subsequent environmental damage that can occur whilst in operation or after its life has long since expired is still not truly understood. It is also foolish to allow so many possible reusable resources to simply be buried in the ground out of sight out of mind. In terms of landfill in general, good management is an essential requirement but alternatively, it should not be considered as a long term feasible option. In contrast, the development of new sustainable technologies that can deal with various types of waste in a clean and efficient way is always going to be an expensive and time consuming goal to achieve. The objective for any government or local/regional authority is to assess what the alternatives are and how they can be realised in the shortest possible time scale. The difficulty with this is that most local governments have not got sufficient financial resources at their disposal. This is mainly due to national government unwillingness to prioritise sustainable practices in the fear of economic repercussions as sacrifices will have to be made at every level of daily life.

Anaerobic digestion provides an important opportunity to generate 100 percent renewable energy from biodegradable waste. Research clearly indicates the most sustainable way to treat our waste is to have separate weekly collections for treatment by anaerobic digestion. Strong backing in the new waste strategy should mean that we start to fulfill this potential, with the widespread introduction of food waste collections and the construction of more anaerobic digestion plants across the UK. The main objectives of anaerobic digestion are to reduce greenhouse gas emissions and to produce "green" energy. Anaerobic digestion can provide a reasonably low technology approach to primary waste treatment which results in energy production and better fertilizer properties than the raw waste.

Recommendation:

- On the balance of evidence that has been presented, that from all three technologies, the Anaerobic Digestion as a disposal of sludge is better than the other two technologies on the basis of different criterion i.e. Labour, Capital Cost, Operating Cost, Process Time, Space requirement, Odours, Energy Balance, Biogas Production, Sludge production, Energy Cost, Reactor Volume, Application, BOD Reduction and Reliability.
- On the basis of calorific value, Anaerobic Digestion has high calorific value so it is better than other two.
- On the basis of cost effectiveness, Anaerobic digestion has low effectiveness cost than the aerobic digestion, but little bit more than landfills.

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