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Review Classification of sludge drying beds SDB (conventional sand drying beds CSDB, Wedge-wire, Solar, and Vacuum assisted and paved drying beds PDB)

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Abstract

Wastewater treatment processes produce large quantities of sludge commonly containing over 90% water. The most important part of sludge treatment prior to disposal is the reduction of the sludge volume by water separation in order to reduce the costs of transportation and handling; numerous techniques had widely fulfilled the basic functional definition of dewatering with varying degrees, and so they referred to significant types of dewatering. For example sludge drying beds; Moisture reduction on the drying bed is lost through percolation and evaporation. Sludge drying beds may be classified into five main types: Conventional sand drying bed (SDB), paved drying bed (PDB), Wedge-Wire, Vacuum assisted and Solar drying bed. Drying beds can be used not only to dewater a particular sludge, but also to dry it to a solids concentration of more than 50–60% and to avoid potential problems from odor and pathogens. When the drying is completed to produce biosolids , these biosolids act as a fertilizer for crop harvesting and soil conditioners. The present work presents a general review on the types of the sludge drying beds.

1. Introduction

1.1. Sludge treatment

The suspended solids, which appear in a wastewater treatment plant, are derived from the raw wastewater. The solid likely contains micro-organisms, which contribute to the transmission of diseases as well as organic and inorganic pollutants. They are toxic and generally have harmful effects on humans and the environment. The amount of sludge produced during wastewater treatment depends on several factors such as climate, culture, consumption habits, treatment technologies etc. [1].These solids commonly termed as “sludge” must be collected from various points in the wastewater treatment process in order to be treated by reducing the water and organic contents and, as a result, rendering them suitable for reuse or final disposal [2; 3; 4].

Every year large amounts of wastewater sludge are produced worldwide. European Commission indicates that while annual sludge production in Europe was 5.5 million tone of dry matter in 1992; it increased to nearly 9 million tones by the end of 2005[5],these amounts are expected to strongly increase up to 13 million tons dry sludge (DS) at the end by 2020. Sludge management (e.g. disposal) and treatment represent more than 50 % of the construction and operating costs of a wastewater treatment plant (WWTP) [6; 7]. According to several recent reports and as recently reviewed by Kelessidis, sludge management is mainly performed in EU by land farming (direct or after composting), incineration (after drying) and landfill [8].

The level and method of sludge treatment are determined based on the type of wastewater treatment process, from which the sludge is generated. The methods involve thickening, dewatering, digestion, and composting [9; 10].

1.1.1 Sludge Thickening

Thickening is the practice of increasing solids content of sludge by the removal of a portion of its liquid content [11; 12]. (Thickening process can enrich 0.8% of DS content of sludge to 4%.The significant volume reduction achieved by sludge concentration via thickening would be beneficial to subsequent treatment processes of digestion, dewatering or final disposal since it reduces the capacity of tanks and equipment required, as well as the operational costs incurred [13]. It could be done by Gravity thickeners, floatation, and Mechanical Thickening [12; 14].

1.1.2 Sludge Digestion

Sludge digestion is typically required after the aerobic process where the sludge may be unstable and requires further treatment.

The specific purpose of digestion includes:-

1. Stabilization of solids
2. Reduction pathogenic organisms,
3. Reduction volume of sludge
4. Obtaining useful by products [2].

Technologies used for stabilization include lime stabilization, heat treatment, aerobic digestion, anaerobic digestion and composting [15].

1.1.3 Sludge Dewatering

Dewatering is a physical unit operation aimed at reducing the moisture content of sludge, the removal of water to the degree that the remaining sludge residue effectively behaves as a solid for handling purposes [11].The minimum solids content at which this is achieved can vary between 16% and 30%[16;17;18]. Its methods are basically sub-divided into two major categories: “mechanical dewatering” and “natural dewatering” [19; 13; 20]. 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 [15].

- Mechanical Dewatering

Mechanical equipment is typically used for dewatering of sludge. It includes the filter press, centrifuge and belt press [14].

- Natural Dewatering

This method refers to the sludge dewatering in open basins where the moisture is removed either by natural evaporation, gravity/induced drainage, or a combination of these [21]. Typically, natural dewatering processes are less complex, easier to operate and require less energy than mechanical systems. However, they are not often preferred because they require a large land area. The success of the dewatering operation depends very much on the local climatic conditions; they are also fairly labor intensive. There are two types of natural dewatering systems available and the most commonly used; "sludge drying beds" and "sludge lagoons" [13; 9; 22].

1.2. Sludge Drying Beds (SDB)

Drying beds have been used since the beginning of the twentieth century [23].Drying of the sludge can be divided into two different stages, namely drainage and evaporation [24; 21]. Drying is the process, which can remove high amount of water from sludge. While thickening and dewatering can remove7% and 35% of the total amount of water, respectively [25]. The design of SDB is mainly based on site specifications, as well as environmental and climatic factors, per capita basis and a unit loading of pounds of dry solids per square foot per year [26] .The sludge drying beds should be located at least 100 m away from houses to avoid potential problems from odor and pathogens [27;2] The main advantages of sludge drying beds are normally the lowest capital cost; When the land is readily available, Small amount of operator attention and skill is required, Low energy consumption, Less sensitive to sludge variability, Low chemical consumption and Higher dry cake solids contents than fully mechanical methods[26;28;29;30;31;25;32] .

- Disadvantages include more land is required than fully mechanical methods, Lack of a rational engineering design approach allowing sound engineering economic analysis, Requires a stabilized sludge, Must be designed with careful concern for climatic effects, Clogging of sand bed, May be more visible to the general public and the removal usually is labor intensive [26; 28; 29; 30; 33; 34; 35].

1.2.1.Dried Sludge Applications

Dried or treated sludge offers a wide range of applications, mainly including agricultural land application. When the drying is completed to produce biosolids, these biosolids act as a fertilizer for crop harvesting, the found organic nitrogen and phosphorous in biosolids are used quite efficiently by crops as the plant nutrients, which are released slowly throughout the growing season. Besides the application of crop harvesting, the treated sludge can be also used as a top dressing on golf course fairways, soil conditioner for construction of parks [36].

1.2.2.Design of sludge drying beds

The design of sludge drying beds involves only the computation of the bed area .This may be done on per capita basis or on solid loading rate basis. When data conforming to the local environmental conditions is not available, the following data may be used:

1. Solid-loading rate: 50 to 150 kg of dry solids per square meter per year.
2. Per capita requirement of bed area (1.6 to 2.3 m2 for digested primary and activated sludge) [21].

1.2.3.Factors affecting on the efficiency of natural drying beds

1. Nature of sludge: Raw sludge and especially those containing high amount of oil or grease, tend to dry slowly by evaporation above a dry solids content of about 30%, while digested sludge crack faster forming a highly fragmented cake which in favorable weather or climate, will produce a dry solid content as high as 70%.
2. Weather and climatic condition: Water evaporates from the sludge slower than the clean water. Sludge dewatering is also at the mercy of rainfall as a moisture reduction through evaporation is minimal in cloudy conditions due to reduced intensity from the sun. A well digested sludge 200-300mm thick can dry within one week or two without odour under favorable climatic condition.
3. Dry initial solid content of sludge: It has often been observed that dispersed particles have a negative effect on the rate of filtration; therefore it is better to consolidate or thicken the sludge before application so as to reduce the proportion of liquor which should be removed through percolation or drainage.
4. Height of applied sludge: This is usually between 150-350mm thick with mechanically lift beds. The depth of application is often 200mm. If the applied depth is too shallow, the thickness of the sludge layer will be small and more applications will be required to deal with a given volume of sludge. Solar intensity, wind velocity and temperature also affect the performance of drying bed though they are often neglected [36; 37; 38].

1.2.4.*Specifications of sludge drying beds components*

1. Under drains it is made from the open joined vitrified clay pipe or tiles of at least 10 cm diameter. Pipe should not be laid more than 6 m apart from each other.
2. Gravel covers the under-drainage system. Graded gravel is placed around the under drains in layers up to 30 cm, with minimum of 15 cm above under drains. Gravel of effective size 3 to 6 mm.

3. Sand of effective size 0.5 to 0.75 mm and uniformity coefficient not greater than 4 is used. The depth of the sand may vary from 20 to 30 cm.
4. Dimensions Sludge drying beds are commonly 6 to 8 m wide and 30 m long. With the bed slope of 0.5% the length should not exceed 30 m for single sludge application point.
5. Sludge Inlet Pipe of minimum 20 cm diameter should be used for sludge inlet pipe. This pipe should discharge sludge at minimum height of 0.3 m above the sand bed. Splash plates should be provided at discharge points to spread the sludge uniformly over the bed and prevent erosion of the sand bed.
6. Removal of Sludge Dried sludge cake is removed by shovel or forks when the moisture content is less than 70%. When the moisture content is less than 40% the sludge is suitable for grinding. [39].

E. d. C. Lampreia [40] studied the mathematical model to develop the design and management of sludge drying beds. This model takes into account the local meteorological conditions (temperature, solar radiation, relative humidity and rainfall) and the initial sludge layer thickness 0.32, 0.2. Laboratory analysis was carried out on samples taken from the beds in order to determine the sludge solids content (SC) evolution. During the course of each cycle, the sludge applied layer thickness was measured as a measure of the volume reduction associated with this process, the determination of the leachate COD and SST values, in order to evaluate the type of treatment it should be submitted to.

It was observed that sludge drying beds present better performance, which means higher values of solids content and consequent reduction of volume in a shorter period of time, in cycles where the air temperature and solar radiation values were higher and relative humidity and precipitation registered values were lower. For the same meteorological conditions, thinner sludge layers were more easily dehydrated. Generically, the predictions obtained by the model showed good agreement with experimental work.

1.2.5.Classification of sludge drying beds

Sludge drying beds may be classified into five main types Conventional sand drying bed, Wedge-Wire, Vacuum assisted, Solar and paved Drying Bed; the following sections describe these types in details [13].

1.2.5.1. Conventional sand drying beds

Sand drying bed is a drying bed supported with drainage channels. Sludge is laid in 200 to 300 mm thickness and allowed to dry. Cycle time for dewatering and drying depends on the applied depth of the sludge, the climatic conditions, temperature and humidity. In general this sludge depth may range in 200 to 450 mm (8 to 18 in), in some systems up to 1 m (3ft) of liquid sludge is applied in the initial layer. Dewatering on sand beds process via two different mechanisms; filtration and evaporation, Water drainage is the most important during the first 1–3 d leaving[21], the solid concentrations as high as 15–25% . Further water removal occurs by evaporation, it is estimated that 60% of the water is drainable [23; 41; 2; 32]. Drying beds are generally used for small and medium sized community or industrial wastewater treatment plants. Although the method is simple and requires minimal operation attention, it has disadvantages due to large area requirement and dependence on climatic conditions [13; 42-44].

This method is based on a simple principle of spreading the sludge out and letting it dry. Where much of the water as possible as is removed by percolation into the under drains and the rest of the water may be allowed to evaporate until the desired solids content is achieved [45]. The number of times that the beds may be used depends on the drying time and the required time to remove the solids. The sludge can then be removed manually to a nearby landfill area. The moisture content can be reduced by about 40% after 10 to 15 days of drying under favorable conditions, sludge loading rate is 100–300 kg dry solids/ m2 /year for uncovered beds and typical sand drying bed construction is shown in (Figure 1).The beds can be built with or without provision for mechanical sludge removal, and with or without a roof [1]. Typical sand beds consist of a layer of coarse sand 15–25 cm in depth and supported on a gravel bed (0.3 –2.5 cm) that incorporates selected tiles or perforated pipe under-drain [31;46-49].

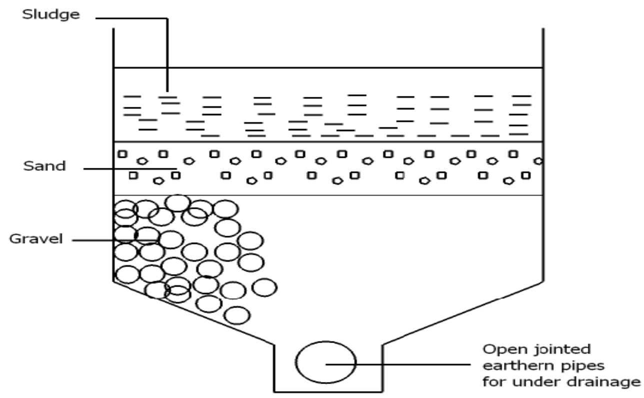

Figure 1: a schematic of a Typical Sludge Drying Bed [1]

1.2.5.1.1. A sand bed's performance depends on

1. Required solids concentration in the dewatered sludge.
2. Solids concentration in the applied sludge.
3. Type of sludge to be applied (e.g., stabilized, thickened, conditioned).
4. Drainage and evaporation rates.

1.2.5.1.2. Operation and Maintenance

The application of sludge treatment methods differs from country to country due to differences in operating conditions and energy prices [50]. Conventional sludge drying is very simple, but trained staff for operation and maintenance is required to ensure proper functioning. This method doesn't require electrical energy [29].

1.2.5.1.3. Cost Considerations

This conventional sludge treatment technology is more land intensive rather than energy intensive. Based on the quantity of wastewater to be treated; size of the sludge drying bed changes. The capital investment for this treatment unit is the highest in terms of the land requirement followed by the construction costs. The O & M requirements include the labour hours, fuel energy, back washing as well as the annual materials and maintenance parts [50].

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1.2.5.1.4. The main problems related to sand drying beds are it's

The problem of using conventional sand drying beds (with 20 – 30 cm sludge layer) is that ,it requires a large area of land for construction, and a period of not less than 10 – 15 days (Depending on Weather conditions such as temperature and humidity) for drying and cleaning. When increasing the height of the layer of sludge; in case of limiting lands, it takes a long period of time (several weeks) until it reaches the degree of drying required. Another problem occurred when using sand drying beds that a loss in the sand layers occurred during the process of cleaning, which requires the compensation of these sands over time. Also one of the main problems facing the use of sand drying beds that it must be cleaned manually without the use of mechanical equipment, which requires the division of beds into large groups of small beds to facilitate the process of cleaning them. These defects and operating problems can be overcome by using the paved drying beds, which is recommended by several studies and determining its design criteria which are suitable for the Egyptian environment. [51].

1.2.5.1.5. Sand drying beds experiences worldwide

An extensive study conducted in Current United States practice is to make drying beds rectangular with dimensions of 15–60 ft (4.5–18 m) wide by 50–150 ft (15–47 m) long with vertical side walls. Usually 4–9 in. (10–23 cm) of sand is placed over 8–18 in. (20–46 cm) of graded gravel or stone. Usually, the sand is 0.012–0.05 in. (0.3–1.2 mm) in effective size and has a uniformity coefficient less than 5. Gravel is normally graded from 1/8 to 1 in. (0.3–2.5 cm), in effective size. Normally, under drain piping has been vitrified clay, but plastic pipe is also becoming acceptable. The pipes shouldn't be less than 4 in. (100 mm), should be spaced 8–20 ft (2.4–6 m) apart, and have a minimum slope of 1%. The piping to the sludge drying beds should be designed for velocity of at-least 0.75 m/s. The sludge is placed on the bed in 20–30 cm layers and allowed to dry [26].

SDBs are being used throughout the world especially in United States since the beginning of the 20th century, but over the years its applicability is limited due to the environmental and climatic factors [52]. In the United States, the majority of Waste Water Treatment Plants (WWTPs) with capacities less than 5 MGD (equal to 18.93 m^3/day) use SDBs. Similarly, Russia and other Eastern European countries use SDBs in more than 80% of the WWTPs [53]. By 2009, Egypt had approx. 303 WWTPs handling 11.85 x106 m^3 /day of sewage. Most of these WWTPs use natural sludge drying beds [30] .

And In Africa, a STP at Cambérène (Dakar, Senegal) uses SDB for sludge treatment since 2006. The initial design under estimated the sludge volumes to be treated and overestimated the sludge concentrations by 40%. This caused serious problems in operations. After detailed study this issue was resolved and the capacities of the SDBs were increased from 200 kg TS/m^2/year to 400 kg TS/m^2/year. Currently, the plant is running at 300 kg TS/m^2/year, thus allowing for an additional bed-scrubbing period of about ten days [54]. Many cities in India including Chennai, Thane, Pune, Patna, Chandigarh, and Bhopal use the conventional sludge drying beds as a part of sludge treatment process. The quantum of sludge to be treated is generally very high due to the amount of wastewater that is generated in these cities. The climatic conditions in India are also favorable for the use of SDBs as the solar energy is available in ample in Indian subcontinent. In the city of Patna, many municipal wastewater treatment plants are using the SDBs as a part of sludge treatment technology. Plants at Beur, Saidpur have installed SDB having total capacity of 405 m^3 each. Furthermore, cities including Raipur, Khurd (Chandigarh), Ahemdabad, Vasna, Rajkot, Vadodara, Surat (located in the state of Gujarat) also have multiple sewage treatment plants, which include sludge drying beds as the treatment units [55]. Further to that The Central Public Health & Environmental Engineering Organisation under Ministry of Urban Development has published the design guidelines for Sludge Drying Beds in India [56] .

F. A. Al-Nozaily et al. [21] studied the possible factors to provide less drying time such as sand type, blocks spacing, Geo-Web support instead of blocks support and the polymer addition. The drying time in the pilot plant ranged 7-10 days. The percolation was the main factor for sludge drying compared to the evaporation of water. The averages were 65% and 35% for percolation and evaporation, respectively. Moreover, 70% of the percolated water took place during first two days; this is in line with Mullick [57]. Has been observed Using a natural (rounded particles) Sa'adah sand (d=0.4-0.8mm) at upper filter layer of the sludge drying beds has perform better than using crushed basalt (angular particles), which being at existing sludge drying beds has an effect on preventing sludge passes through filter layer and finally cause clogging drainage system. Using blocks support has no significant effect on drying time compared to more surface filtration area. Increasing the blocks spacing (filtration area) has a significant effect on drying time especially at rainfall season which can filtrate the excess water that came from rainfall precipitation, therefore we can conclude that using of geo-web support which provided the higher filtration area at rainfall .The polymer addition has no considerable effect on overall drying time probably due to the small scale of pilot plant.

Radaideh et al. [58] studied the compare the efficiency of sand drying beds to dewater sludge digested anaerobically against sludge digested in the aerobic/anoxic stages in extended aeration (EA) plants. Full and lab scale experiments have shown that aerobically digested sludge in extended aeration plants has better dewatering efficiency on sand drying beds than anaerobically digested sludge. This was shown by comparing a number of parameters that are usually used to characterize the dewaterability of wastewater sludge's. They included dry solids content, capillary suction time (CST), sludge volume index (SVI), volatile and fixed solids, particle size distribution, fraction of small particles (fines) and drainage test. It is recommended that sand drying beds be used in Jordan for extended aeration plants as these produce low volumes of sludge that has better dewatering properties than anaerobically digested sludge.

Saleh Al-Muzaini [59] studied the examine the present dewatering facilities at the Jahra treatment plant and to measure the pollutant levels in the produced sludge in order to assess the overall performance of the sand drying bed facilities. Laboratory results for the sludge produced at the Jahra plant showed that organic matter and sand content are high, and heavy metals contents are low. Based on the results, using sand-drying-bed technologies for dewatering at the Jahra plant will be difficult. Furthermore, sand-drying beds always face problems with clogging of the sand layer. In addition, the sand quality in drying beds sometimes does not conform to standard specifications, allowing escape of the fine sand particles into the drainage system, clogging the drainage system. Suitable options for sludge dewatering equipment are recommended, but an effective mechanical investigation should be conducted. Therefore, a pilot mechanical dewatering facility should be established to provide the capacity for simultaneous exploration of various mechanical dewatering systems such as belt filter press, centrifuge, and vacuum filtration.

Mehrdadi et al. [36] studied the an experimental investigation was carried out to assess the efficacy of solar energy for drying of sludge from pharmaceutical industrial waste over a sand bed covered(SSDSB)as compared to the conventional sludge drying over a sand bed (CSDSB) . Most of the moisture content was lost by drainage in first 3-4 days and the solar sludge drying sand bed (SSDSB) reduced drying time by about 25- 35% as compared to the conventional sludge drying sand bed(CSDSB). The sludge loading rates were observed to be about 138.5 kg solids/m2/year and 99.5 kg solids/m2/year for SSDSB and CSDSB respectively. It may be concluded that the condensate water from SSDSB was of excellent quality for several probable reuses.

According to J. A. Radaidah et al. [39] Intensive solar collector cells are being employed to increase the efficiency of existing conventional sand beds, with the aim to avoid expansion of drying beds. This solar energy is used to heat water that passes through galvanized pipes at the bottom of the sand drying beds , Sludge that is applied to beds will become heated. This will enhance evaporation, accelerate dewatering of sludge and help in the reduction of pathogenic levels. Obtained results indicated that the water content of samples decreased from 96.5 % to 32.94 % within 18 days when conventional sand drying beds were used. By modified beds only 60 % of this time was required.The increase of sludge temperature also leads to reduce the microbiological content of sludge. 100 % removal of some pathogenic species (fecal coliforms) was achieved; other contaminants and pathogens could be reduced to 99 %. The modified sludge bed reduced drying time by about 35% as compared to the conventional sludge bend, thus increasing the loading factor of beds by ~ 30 %.

Cofiea et al. [60] investigated the use of drying beds in separating solid and liquid fractions of faecal sludge (FS) so that the solids can be cocomposted and the organic matter and part of the nutrients captured for urban agriculture. The loading rate of sludge ranged from 196 to 321 kg total solids (TS) /m2 y. Biosolids with (TS) 20% were obtained after an average drying time of 2 weeks. During FS dewatering, percentage reduction in concentrations of solids and organic constituents was above 80%. This shows that drying beds are effective in achieving solids–liquid separation of FS withholding on average, 96% of the SS. Hundred percent of the helminth eggs were withheld on the drying beds.

A. Masmoudi [61] studied the experimental data about sewage sludge drying through a pilot scale drying bed, during winter, spring and summer. To achieve a moisture content of 0.15 kg water /kg DS, the drying period of the 2 cm thickness sludge layer was 14 days in winter, 5 days in spring and 4 days in summer. The dry solid content (DS) increased from 4.1% to 87.25% in winter, 4.8% to 87% in spring and from 4% to 87% in summer. The sludge volume was reduced up to 95 % in the three seasons. The maximum drying rate value observed in spring was 0.38 kg water/ kg DS.h and 0.97 kg water/ kg DS.h in summer. This rate was not calculated in winter because of the moisture content‘s irregular variation.

1.2.5.2. Wedge-wire drying beds

Since the 1960s, Wedge-wire drying bed has been successfully used in England to dewater both municipal and industrial wastewater sludge, Used in the United States since the early 1970s [2; 41].

In wedge-wire drying beds, artificial media made of stainless steel wire wedge and high-density polyurethane formed into panels have been successfully utilized. Drainage and evaporation are the two mechanisms utilized to form a sludge cake [23] .

A typical cross section of a wedge-wire bed is shown in (Figure 2).The bed consists of a shallow rectangular watertight basin fitted with a false floor of wedge water panels. These panels have slotted openings of 0.01 in. (0.25 mm). This false floor is made watertight with caulking where the panels about the walls. An outlet valve to control the rate of drainage is located underneath the false floor [62]. The U.S. EPA reported the following advantages for the system: no clogging of the media, constant and rapid drainage, higher throughput rate than sand beds, easier removal of sludge cake, ability of drying difficult to dewater sludge and ease of maintenance. [63; 33] .

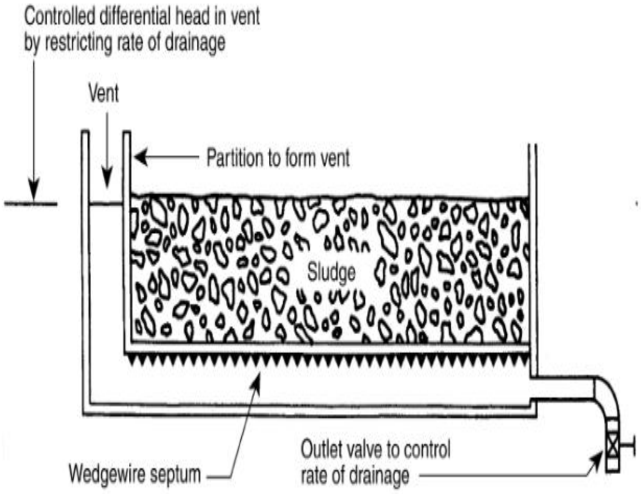

Figure 2: a schematic of a Cross-section of a wedge-wire drying bed [33]

1.2.5.3. Vacuum assisted

The only operating vacuum-assisted drying beds at this time are two 20 ft (6m) by 40 ft (12m) units built in 1976 at Sunrise city, Florida. They dewater an aerobically digested sludge having 2% solid concentration, which is wasted from a stabilization wastewater treatment plant [64; 2].

1.2.5.3.1. The principal components of the Sunrise facility are as following

1. A bottom ground slab consisting of reinforced concrete.
2. A layer of stabilized aggregate several inches thick which provide support for the rigid multimedia filter top. This space is also the vacuum chamber and is connected to a vacuum pump.
3. A rigid multi-media filter top is placed on the aggregate support. Sludge is then applied to the surface of this media [13].

1.2.5.3.2. The operating sequence is as following

1. Sludge is introduced onto the filter surface by gravity flow at the rate of 150 gpm (9.4 L/s) and to a depth of 12–18 in. (30–46 cm).
2. Filtrate drains through the multi-media filter and into the space containing the aggregates and then to a sump, from which it is pumped back to the plant by a self-actuated submersible pump.
3. As soon as the entire surface of the multi-media filter is covered with sludge, the vacuum system is started and vacuum is maintained at 1–10 in. Hg (3–34 kN/m2).

Under favorable weather conditions, this system dewaters the dilute aerobically digested sludge to a 12% solids concentration in 24 h without polymer addition, and to the same level in 8 h if polymer is added. This particular sludge of 12% solids concentration is capable of being lifted from the bed by a fork or mechanical equipment. The sludge will further dewater to about 20% solids concentration in 48 h [23; 65].

1.2.5.3.3. Process performance and theory

A cake of 40–45% solids might be achieved in 2–6 wk. in good weather and with well-digested secondary, primary, or mixed sludge. With chemical conditioning, dewatering time may be reduced by

50% or more. Solids contents as high 85–90% have been achieved on sand beds, but normally, the required times to achieve such dry sludge cakes are impractical. The mechanisms for water removal impose a number of operating variables that affect the design of drying beds, such as:

1. Sludge condition.
2. Sludge characteristics.
3. Soil permeability.
4. Land availability and cost [65].

However, Air temperature, relative humidity, percentage of sunshine, and wind velocity also affect the rate of water evaporation. In the summer or at high temperature and humidity, the rate of drying is two to three times faster than in the winter or at low temperature [66]. It is noteworthy that in many wastewater treatment plants sludge is stored in digesters in the winter and dried only in the summer [65].

1.2.5.4. Solar drying beds

Solar drying is one of the oldest drying techniques in which solar radiation is used; solar drying does not require man produced energy [67].

This bed type utilizes energy from the sun to achieve dewatering operation and drying. It makes use of sophisticated technology like that of GREEN HOUSE [2; 68].

According to Mayis kurt [69] demonstrates that solar panels can be used as auxiliary heat source for a Solar Dryer (GSD) instead of a thermal dryer if enough area, solar radiation, ventilation and mixing of sludge is provided. The results indicated that water removal from WWTP sludge with solar panels is less economical compare to water removal with Greenhouse Solar Dryer (GSD) and investment cost of thermal dryer systems. However, it is economical option when comparing it with energy requirement cost.

Salihoğlu et al., [70] study the limited liming & solar drying as an alternative to only liming the mechanically dewatered sludge. Open and covered solar sludge drying plants were constructed in pilot scale for experimental purposes. Dry solids and climatic conditions were constantly measured; faecal coliform reduction was also monitored. The specially designed covered solar drying plant proved to be more efficient than the open plant in terms of drying and faecal coliform reduction. It was found that, if the limited liming & solar drying method was applied after mechanical dewatering instead of only-liming method, the total amount of the sludge to be disposed would be reduced by approximately 40%. This would lead to a reduction in the transportation, handling, and landfilling costs. The covered solar drying system can be applied in cities receiving high solar radiation. It provides regulated indoor conditions for controlling emission, odor, and lower energy costs and higher drying performance can be obtained.

1.2.5.5. Paved drying beds

Since the 1950s, Paved drying beds have had limited use. (Figure 3) shows typical paved drying bed construction. Normally, the beds are rectangular in shape and are 20–50 ft (5–15 m) wide by 70–150 ft (21–46 m) long with vertical sidewalls [2].Current practice is to use either concrete or asphalt lining. Normally, the lining rests on an 8–12 in. (20–30 cm) build up sand or gravel base. The lining should have a minimum of 1.5% slope to the drainage area. An unpaved area, 2–3 ft (0.60–1 m) wide is placed along either side or down the middle for drainage. A minimum 4 in. (100 mm) diameter pipe is used to convey drainage water away [23]. Paved beds have worked successfully with anaerobically digested sludge's but are less desirable than sand beds for aerobically digested activated sludge [51] . The use of digested or otherwise stabilized, sludge is necessary to avoid odor complaints and to satisfy regulatory requirements for final sludge disposal.

If sludge-settling properties are good, it is possible to remove 20-30% of water from sludge; drying period depends on climatic conditions [41].

The key advantage of this type of bed is the ability to use mechanical equipment for sludge removal without causing damage to under drain pipes or loss of sand, shorter drying times as well as more economical operation when compared with conventional sand drying beds. The main disadvantages are high capital cost and a larger land area requirement than for conventional sand drying beds [33].

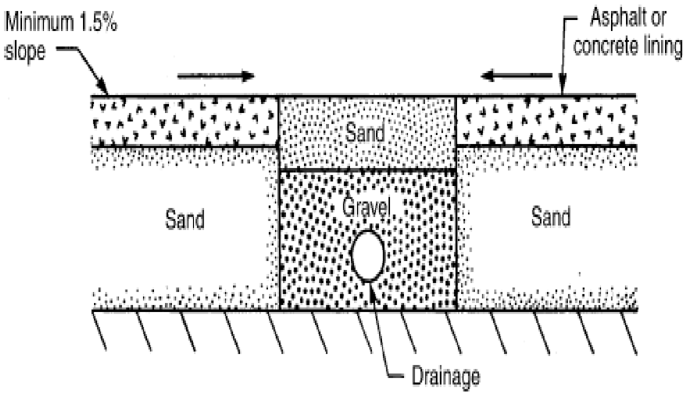

Figure 3: a schematic of atypical Paved Drying Bed [18]

Recent improvements to the paved bed process utilize a tractor-mounted horizontal auger, or other device, to regularly mix and aerate the sludge. This mixing and aeration breaks up the surface crust that inhibits evaporation, allowing more rapid dewatering than conventional sand beds. Some of the equipment was originally developed for composting operations but serves equally well for paved bed dewatering. Under drained beds are still used in some locations, but the most cost effective approach in suitable climates is to construct a low cost impermeable paved bed and depend on decantation of supernatant and auger/aeration mixing for evaporation to reach the necessary dewatering level [71] .

1.2.5.5.1. Specifications

Studied the wall of drying beds must be water tight and should extend to 300 mm to 600 mm above and should not be less than 150 mm below the surface of the bed, an impermeable concrete pad must be installed over a liner. Sand Media Beds: should have at least 300mm sand bed with coefficient of uniformity of less than 4.0 and effective grain size of not less than 0.3mm. The sand above the top of the under drain should not be above 75mm thick.

Gravel Media Bed: the top layer of gravel media bed must be at least 75mm thick and of size between 3.1mm and 6.3mm [2].

1.2.5.5.2. Design Considerations

The critical design parameter for paved beds, as with sand beds and drying lagoons, is the surface area required to dewater the sludge to the specified solids level in the specified time. Since drainage is not a factor in many modern paved bed designs, the only ways water can be removed is through decantation and evaporation. Paved beds can be used in any location, but since evaporation provides the major pathway for water loss, they work best in warm, arid and semi-arid climates. Assuming the same degree of effort with the auger/ aerator, the design solids loading on a bed, or the bed area will be directly related to the potential evaporation, and precipitation in the local area. The design loading rate for the system in Roswell, NM, is 244 kg/m^2/yr (50 lb/ft^2/yr); the loading during a pilot test in Wichita, KS, was 127 kg/m^2/yr (26 lb/ft^2/yr). In more humid climates the allowable loading might be even lower [72].

A study in New Mexico indicated that the evaporation rate from mixed and aerated sludge was about 58.7 percent of the free water pan evaporation tor the site. That relationship should be generally valid for other locations also. At large scale projects, where land costs can be very significant, a pilot test to determine this ratio should be used to optimize the design [72].

1.2.5.5.3. Structural Elements

Paved beds have been constructed with concrete and asphalt pavement, with and without drains. However, the most economical approach may be to use soil cement as the paved surface. Information on construction of soil cement pavements can be obtained from the Portland Cement Association. A long rectangular configuration improves efficiency by reducing the time required for turning the auger/aerator vehicle. A variety of inlet and decantation structures are also possible. The minimum total depth of the bed is about 0.8 m (2.6 ft) to provide some free board above the typical 30 cm (12 in) sludge layer. In some systems up to 1 m (3 ft) of liquid sludge is applied in the initial layer .Other major system components include the sludge and decantation piping, and the auger/aerator vehicles [70] (EPA, 1985). Field experience indicates that the use of paved drying beds results in shorter drying times as well as more economical operation when compared with conventional sand drying beds, Paved beds have worked successfully with anaerobically digested sludge's but are less desirable than sand beds for aerobically digested activated sludge[51] .

1.2.5.5.4. Performance Expectations

The use of digested or otherwise stabilized, sludge is necessary to avoid odor complaints and to satisfy regulatory requirements for final sludge disposal. The decantation phase might require 2 to 3 days for sludge settling and 1 to 2 days to decant each increment of sludge added. Depending on the sludge characteristics, It drainage is allowed by the design. It should also be essentially complete during the time allowed for sludge settling and decantation.

The final evaporative drying period will depend on the climatic conditions occurring after the sludge is applied and on the regular use of the auger/aerator equipment. Solids in the range of 40 to 50 percent can be achieved in 30 to 40 days in an arid climate, for a 30 cm (12 in) sludge layer, depending on the time of year and the effectiveness of decantation [72].

A 1 m (3 ft) sludge layer in the same climate might require 100 to 250 days to reach 50 percent solids, depending on when the sludge was applied [73;74] .

1.2.5.5.5. Operation and Maintenance

The major operational tasks are sludge application, decantation, mixing and aeration, and sludge removal. Depending on the size of the operation and the time at year, the sludge on the bed should be mixed several times a week to maintain optimum evaporation conditions. Labor requirements at the Roswell, NM system are estimated to be about 0.3 hr/yr per Mg of dry solids processed [72].

Maintenance requirements include routine care of the auger/aeration equipment, the sludge pumping and piping network, the decantation piping, and the bed and dikes. If the site experiences freezing weather in the winter months, the valves and pumps in the system need to be protected and checked periodically during the critical freezing periods.

1.2.5.5.6. Costs

Capital costs are strongly influenced by the cost of land at the project site. Other major capital costs include the containing walls and pavement, application and decantation piping (and drainage piping if used), the auger/aerator, and the sludge removal equipment .The major O & M costs are labor and fuel for the equipment [72].

D. V. Manfioh et al. [75] studied the compare the dewatering of septic tank sludge using conventional sludge drying bed (CSDB) and a sludge drying bed with permeable pavement (SDBPP). At the same time of dewatering, the volume drained by the SDBPP was 37.4±4.6% higher than that obtained in the CSDB. Therefore, a lower drying bed could be used. However, it provided a sludge cake with a similar concentration of solids as the one obtained in the conventional bed (CSDB). It was found that the use of synthetic polymer allowed dewatering to occur in less time, this would result in more drying cycles in the same bed area, or in the size reduction of the sludge drying beds if the same volume of sludge is employed, The use or not of polymer does not interfere in the solids content of the cake.The reuse of the pavement was proven possible, but required large volumes of water and mechanical equipment. The use of a Sludge drying bed with permeable pavement (SDBPP) or a Sludge drying bed composed of permeable pavement plus a layer of sand (SDBS) showed no significant difference between the volume dewatered regarding the humidity in the sludge cake and the maintenance. Thus, in this alternative system, adding sand to the pavement (SDBS) would be unnecessary.

Lienard et al. [73] studied dewatering of activated sludge in experimental reed-planted and unplanted sludge concrete drying beds. They concluded that reeds were found to contribute to maintaining a high and regular liquid conductivity in the sludge, which allows easier and higher dosing of planted beds. Solids concentration may range between 40 to 50 percent for 30–40 days of drying period in an arid climate for a 30 cm sludge layer [72].

Conclusion

The literature review revealed that the sludge contains micro-organisms, which contribute to the transmission of diseases as well as organic and inorganic pollutants they are toxic and generally have harmful effects on humans and the environment. Must be collected in order to be treated by reducing its water content and organic matter and, as a result rendering them suitable for reuse or final disposal ,This is done by dewatering. There are two types of dewatering; sludge drying beds and sludge lagoons. Many researches have been conducted to investigate beneficial uses of sludge drying beds. Moisture reduction on the drying bed is through percolation and evaporation, Solid-loading rate (50 to 300 kg/m2/year). Drying beds have many advantages; less complex, easier to operate, and require less operational energy than mechanical dewatering systems, Low energy consumption, less sensitive to sludge variability, Low chemical consumption. The design of sludge drying beds is based mainly on site specifications, as well as environmental and climatic factors. The sludge drying beds are divided into; Conventional sand drying bed (SDB), paved drying bed (PDB), Wedge-Wire, Vacuum assisted and Solar drying bed. The key advantage of paved bed is the ability to use mechanical equipment for sludge removal without causing damage to under drain pipes or loss of sand, shorter drying times as well as more economical operation when compared with conventional sand drying beds, Solar drying beds it is economical, does not require man produced energy and advantage of wedge-wire no clogging of the media, constant and rapid drainage, higher throughput rate than sand beds and ease of maintenance.

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