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A STUDY OF FAECAL COLIFORM DIE-OFF IN SEWAGE SLUDGE DRYING BED

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ABSTRACT

The aim of this study was to assess the interacting characteristics of sewage sludge such as temperature, pH, and moisture content of sludge at defined time intervals as to how they affect Coliform die-off in a drying bed. Samples were collected at 0.0mm depth (i.e. surface of sludge), 60mm, 120mm, 180mm and 240mm, and colony count tests were performed on the samples. Results indicate that the number of Coliforms was minimum at the surface, maximum at 60mm depth, and decreased consistently to another minimum value at 240mm depth. This trend could be as a result of the organisms being in their exponential phase with adequate nutrients and growth conditions at 60mm depth, which later experienced decrease in available nutrients, oxygen and unfavorable growth conditions such as unfavorable temperatures, reduced moisture content, acidic pH and water activity. Range of the maxima and minima values of CFU/100ml for the five horizons considered over a period of 76 days were $0.122 \times 10^7, 1.240 \times 10^7, 1.160 \times 10^7, 1.460 \times 10^7,$ ***and*** 1.580×10^7. ***This finding does not conform with the work of Al Malack and others [6] because from their results, the various pathogenic organisms studied were found to survive longer as the sludge initial depth was increased. Short-term and long-term effect of drying indicate that low moisture content favours microbial decay because pathogen removal rate was consistently increasing from 21/01/2013 to 08/02/3013, a condition which started prevailing when the moisture content of sludge in the drying bed had decreased from 88.99 per cent on 29/11/2012 to 65.48 per cent on 21/01/2013. It was recommended that conditioners should be used to dewater sludge faster in order to speed-up pathogen die-off rate in drying beds.***

Keywords: *Assessment, Coliform die-off, Sludge drying bed*

1. INTRODUCTION

With respect to the study on faecal coliform die-off in sewage sludge drying bed, and up to the knowledge of the author, there is no single work in that direction. Based on that, the main objective of the study was to investigate faecal coliform die-off in sewage sludge drying bed. The outcome of this research will aid environmental engineers in the management of sewage sludge derived by households' wastes.

Huge quantities of sewage sludge are generated annually, globally, but the serious problem lies in finding the most effective method of managing and disposing of these wastes in order to reduce degradation of the environment. For instance, disposal into receiving waters will give rise to eutrophication, algal bloom and destruction of aquatic lives by suffocation due to the high BOD exerted by aerobic microorganisms, and consequently destabilization of aquatic ecosystems and biodiversity. On the other side, disposal at dump sites will attract insect transmitting diseases and rodents in addition to very offensive odour.

Drying beds are either planted or unplanted sealed shallow ponds filled with several drainage layers and designed for the separation of the solid fraction of (faecal) sludge from latrines, septic tanks, biogas reactors, trickling filters etc. Sludge is dried naturally by combination of percolation and evaporation from solar radiation. An understanding of the interacting characteristics of sewage sludge such as pH, pathogen die-off, temperature and moisture content is fundamental to formulating policies and effective management techniques for wastes derived by septic systems. Dewatering and disposal of waste sludge is a major economical factor in the operation of wastewater treatment plants. Mikkelsen and Keiding [1], reported that 30-50% of annual operating costs

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are related to sludge dewatering alone. Over 6,000 wastewater plants use the conventional sludge drying sand bed and many cities with population of over 100,000 use drying beds [2]. Little researches have been done in the utilization of solar energy for sludge drying. No information is available regarding the possible reuse of evaporated water from the sludge [3]. Quon and Tambign [4] utilized the radiant energy emitted by six 300 watt reflector flood light to dry sludge and found that the average rate of evaporation from a sludge surface was $0.89 \times 10^{-3} gm/cm^2/min.$ at radiant intensity of $1.10 cal/cm^2$/min. Chao, et al [5] studied a simple transparent structure similar to a greenhouse which can be used to generate hot air from available solar energy for drying industrial sludge. The moisture content of 200kg sludge could be reduced from 75% to around 30-33% in a five day operating period. Al-Malack, et al [6] conducted an extensive research in order to determine the microbiological characteristics of municipal sludges produced at three major cities, namely, Qateef, Damman, and Khobar in the Eastern province of Saudi Arabia. The results indicated that municipal sludge produced at the three cities was not suitable for utilization in agricultural activities due to high levels of salmonella even after 14 days of drying at Qateef wastewater treatment plant. Dried sludge samples collected from Qateef, Damman and Khobar were found to contain salmonella species on the average of 22, 107 and 127 MPN per gram of dried sludge respectively. The paper [7] investigated the effects of moisture and temperature on the inactivation rate of faecal coliform in biosolids and developed a mathematical model to predict their level in biosolids in solar drying beds at any time during the drying process. They reported that temperature and moisture had significant main and interactive effects on the inactivation of rate of *Escherichia coli* in biosolids. The results also showed that observed and predicted inactivation correlated well ($R^2 = 0.81$). With respect to survival of pathogens in drying beds, [8] investigated the use of drying beds with municipal sludge. They reported that drying beds were found to retain 80 per cent of solids and 100 per cent of helminth eggs. The paper [9] investigated the survival of *faecal coliforms* in activated sludge after dewatering in drying beds. They reported that the treatment of sludge in drying beds appeared to be efficient in eliminating pathogenic micro-organisms such as *faecal coliforms, protozoan cysts* and helminth eggs.[10] investigated the survival of eggs of *A. suum* in two sludge drying beds of sewage treatmet plants (STP) under different climatic-geographical conditions. They reported that sludge drying beds of both sewage treatment plants showed different survival of eggs. In one of the STPs, a rapid reduction in viable eggs was reported (from 80.4 to 19.8 per cent). Later this decrease became less rapid and at the end of the experiment, after 240 days only 5 per cent of eggs were viable. In the other STP, the viability of eggs was reduced rather gradually, and after 320 days of exposure 36 per cent of viable *A. suum* eggs were still recorded

The approximate average capacity of a rural sewage facility is the domestic wastewater of 1000 persons [11], which is estimated to be approximately 300 – $330 m^3\ d^{-1}$of wastewater and municipal wastewater treatment plant serving large population, huge volumes of wastewater is produced.

Therefore, the aim of this study was also to assess the interaction of the above stated sludge characteristics that affect microbial activity and pathogen die-off trend in sewage sludge drying bed. It is important to note that low operation and maintenance costs coupled with effective pathogen removal have made drying beds widespread all over the world as an effective means of treating sewage sludge. The pathogen removal mechanisms involve a series of complex physical, chemical and biological interactions that occur naturally in aquatic systems. The most significant mechanisms causing decay involve (i) DNA damage caused by the formation of sunlight ultraviolet irradiation [12]; (ii) photo-oxidation caused by the formation of singlet oxygen, hydrogen peroxide and other super-oxide and hydroxyle radicals due to humic substances adsorbing light and passing to oxygen; (iii) predation and starvation due to lack of nutrients or carbon source [13, 14] and (iv) algal toxins [15].

Up to now, *E. Coli* and faecal Coliforms (FC) have been the most widely used microorganism indicators in investigating the inactivation mechanisms in the lagoons, as they can be readily and reliably identified and enumerated [16]. Coliform decay is usually considered to follow first order kinetics:

$$dN/dt = -kN, \quad (1)$$

Where N is effluent bacterial concentrations; t is mean hydraulic retention time (day); k is die-off coefficient *(day-1)*. Thus, assuming ideal hydraulic flow patterns, the bacterial removal in an individual lagoon is expressed through frequently used formulae:

$$N = N_0 e^{-kt} \quad (2)$$

For plug- flow pattern and closed lagoon. Where N_0 is the influent Coliform concentration.

$$N = \frac{N}{(1+kt)} \quad (3)$$

For completely stirred tank reactor (CSTR) pattern. The CSTR hydraulic model is the most widely used in engineering design.

Many studies assumed that temperature was the most important factor determining pathogen decay [17 – 21]. The widely used expression of k as a function of temperature was given by [22].

$$k_T = k_{20} \times \theta^{(T-20)} \quad (4)$$

Where $\boldsymbol{\theta}$ is temperature coefficient; T is water temperature (^{0}C); k_T *and* k_{20} are die-off coefficients at any given temperature T *and at* 20^0C. (day^{-1}), die-off coefficient is a factor which expresses the ratio of bacterial die-off to temperature. It is recognized that these $\boldsymbol{\theta}$ and k_{20} values reported in this literature scatter appreciably. This implies that the temperature would not be the sole factor influencing bacterial die-off coefficients and other factors should be taken into consideration [23 – 25].

2. MATERIALS AND METHODS

2.1 Seepage and Evaporation Experiments

The drying bed is a simple sand and gravel filters on which batch loads of sludge are dewatered. Generally, the gravel layer (grain diameter of 7 – 15mm) of 20cm thick was used, and this is followed by a final sand layer (grain diameter of 0.2 – 0.6mm). The dimensions of the prototype model (i.e. the drying bed) is 100cm long, 30cm wide, 70cm deep, this is shown in Figures 1 and 2 below, the drain pipe is 50mm and the length extending into the bed is perforated so that filtration can take place. An evaporation can of 15cm surface diameter and 20cm depth was kept by the side of the drying bed and was used to measure evaporation.

The first experiment was determination of the moisture content of the sewage sludge used for the study, which served as a benchmark before addition of given quantity of water to enhance flow ability. Moisture content of sludge was determined in accordance with [26], and in this experiment, 2.0155g sludge sample was oven dried at 105^{o}C, and moisture content was calculated after the difference between two successive weighing was not more than 0.1%.Further to that, 60.95kg of sludge containing 49.37kg of water based on 81.01% moisture content was weighed using model NT 100kg/220lbs capacity weighing balance and placed inside a container (150 litres capacity PVC drum) , 64.05kg of water was added to the sludge so that the moisture content increased from 81.01% to 90.74%. The contents were thoroughly stirred to a uniform consistency before application into the drying bed.

Sludge were applied on the bed intermittently and the percolate collected at 24 hours interval for 15 days. Two hours after the final application of sludge on the bed, 1638.0g of sludge was collected from the bed and placed inside the evaporation can, kept by the side of the bed and evaporation allowed to take place for 15 days also, readings were taken at 24 hours interval and simultaneously with seepage. Since evaporation is directly proportional to surface area [28], evaporation from the drying bed was determined by multiplying the evaporation from the evaporation can by the area ratio A_{db}/A_{ec} where A_{db} and A_{ec}, are the surface areas of the drying bed and evaporation can respectively. This method was used to measure evaporation from the bed because of unavailability of evaporation meter which is a major limitation in this research. An evaporation can of surface diameter $\phi = 15cm$ was used in performing evaporation experiment. The corresponding evaporation from the drying bed was determined by introducing the area ratio which also apply on dimensional analysis [28].. Area ratio, $A_r = A_{db}/A_{ec}$, , in which A_{ec} is the surface area of the evaporation can and A_{db} the surface area of the drying bed. Surface diameter of the evaporation can , $\phi = 15cm$, so that surface area of the evaporation can A_{ec} is given by, $A_{ec} = \frac{\pi}{4}d^2 = \frac{\pi}{4}.15^2 = 176.67cm^2$

Dimension of the drying bed $= 100cm \times 30cm. A_{db} = 100 \times 3000cm^2$, $A_r = \frac{3000}{176.67} = 16.98$. Therefore, to determine the corresponding evaporation in the drying bed, values of evaporation from the evaporation can were multiplied by the factor 16.98.

2.2 Colony Count Experiment

Sewage sludge samples were collected at the surface (i.e. 0mm depth), 60mm, 120mm, 180mm and 240mm depths at different time intervals over a period of 71 days and subjected to colony count test in order to predict bacterial die-off due to solar radiation with time.

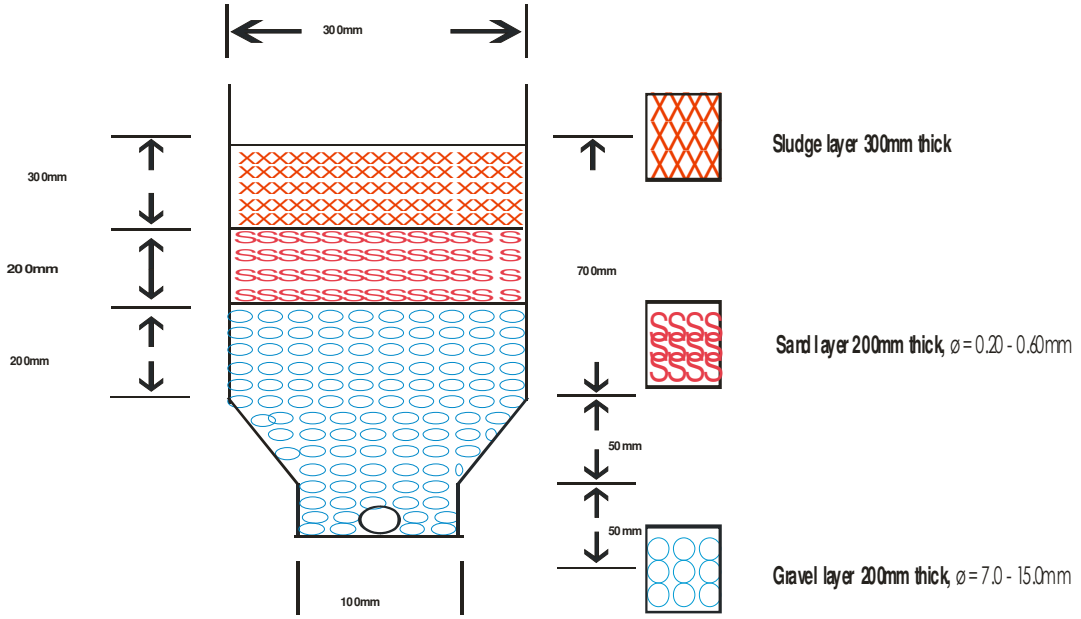

Figure 1: Cross sectional view of drying bed`

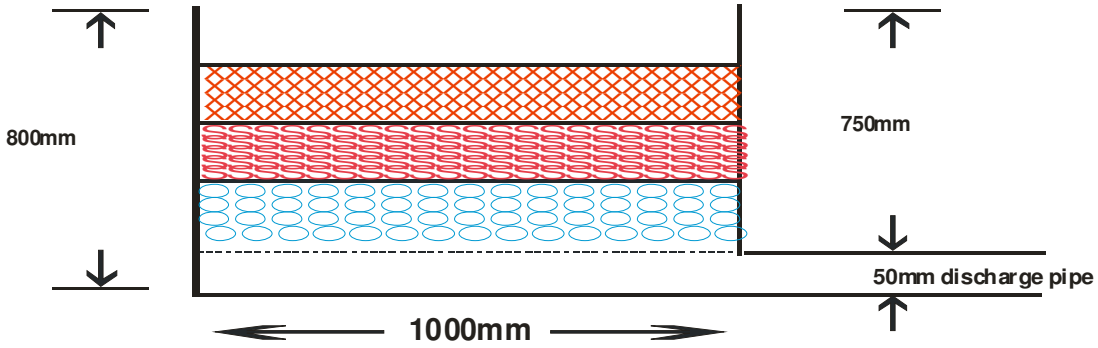

Figure 2: Longitudinal view of drying bed

Four samples were collected at close range time intervals between 29/11/2012 and 10/12/2012 in order to predict short time effects of microbial die-off. A long period of 45 days elapsed before six samples were collected starting from 14/01/2013 to 04/02/2013 so as to assess the long term effect of exposure to solar radiation. In this test, 1.0g of the sample each was taken and diluted in 9.0ml of sterile water and serial dilution was performed. 1.0ml was taken from the inoculums used which were 10^{-3},10^{-4} and 10^{-5}, and in duplicates and inoculated into a Petri dish and then 15.0ml of sterile molten nutrient agar was poured and thoroughly mixed by rotating clockwise and anti- clockwise, allowed to gel and then incubated in an incubator at 35^0C for 24 hours. Confluence growth was experienced when the inoculums was10^{-3}, whose range was between 500CFU to about 700CFU, optimum growth was noticed at inoculums 10^{-4}which ranged from 30CFU to 300CFU while very minimal growth took place at inoculums 10^{-5},the range was between 11CFU and 25CFU.Therefore, inoculums $10^{-4}$was used to determine the colony forming units in this study. The emerged organisms were counted using only inoculums 10^{-4}which are plates containing 30 to 300 colonies and expressed as colony forming units (CFU). CFU were determined using the expression;

$$CFU = \frac{N_c}{V_p \times D_f} \quad (5)$$

Where, N_c is the number of colonies, V_p is the volume of pipette and D_f is the dilution factor

At different days of sampling, ambient temperatures, temperatures and pH values of sludge at various depths starting from the surface (i.e. 0.0mm depth), 60mm, 120mm, 180mm and 240mm depths were measured using an LCD portable digital multi-thermometer with external sensor probe, model No. ST-9283A/B/C and a pHep$^{(R)}$ Pocket-sized pH meter. Also, moisture content of sludge were computed at various sampling dates in accordance with [27].

The sectional views of the experimental set up for sludge drying bed are shown in Figure 1 and Figure 2 respectively.

3. RESULTS

The results derived from this study are presented in figures 3 and 4, figure 3 is a plot of the variation of colony forming units with time and sampling depths while figure 4 is a plot of the variation of colony forming units with sampling depths at various dates. Table 1 is the relationships between temperatures, sludge depths and time, table 2 is the relationship between moisture content of sewage and time and table 3 is the relationship between pH values, time and sampling depths.

Table 1: Relationships between temperatures, sludge depths and time

Depth (mm)	Temperature (^0C)									
	29/11/12	03/12/12	06/12/12	10/12/12	14/01/13	17/01/13	21/01/13	28/01/13	31/01/13	04/02/13
	26.8 [b]	26.7 [b]	25.3 [b]	26.6 [b]	23.5 [b]	27.7 [b]	27.4 [b]	22.4 [b]	25.2 [b]	25.7 [b]
0	27.7	27.9	27.5	29.2	24.3	28.1	28.6	23.3	26.3	25.5
60	28.6	30.3	30.1	31.5	24.0	28.8	29.0	23.4	26.0	24.4
120	29.1	30.0	29.9	31.4	24.0	29.3	29.3	23.3	26.0	23.8
180	28.2	29.1	28.8	30.3	24.0	29.3	29.2	23.2	26.0	23.7
240	27.6	28.6	27.9	29.9	23.8	28.8	28.7	23.0	25.9	23.9

[b] Ambient temperatures at various days of sampling

Table 2: Relationship between moisture content of sewage and time

Day	q_{ec}	$q_e(\times 10^{-3}m^3)$	Seepage (S) $(\times 10^{-3})m^3$	$q_e + S(\times 10^{-3})m^3$	Moisture content of sludge (%)	Date of sampling
0	0	0	0	0	88.99	29/11/2012
1	159	2699.82	19641	22340.82	86.02	03/12/2012
2	128	2173.44	10936	13109.44	83.39	06/12/2012
3	120	2037.60	6823	8860.60	80.97	10/12/2012
4	125	2122.50	4087	6209.50	78.80	14/01/2013
5	62	1052.76	2192	3244.76	68.31	17/01/2013
6	52	882.96	2121	3003.96	65.48	21/01/2013
7	51	865.98	2067	2932.98	62.17	28/01/2013
8	42	713.16	2011	2724.16	58.47	31/01/2013
9	38	645.24	1933	2578.24	54.24	04/02/2013
10	37	628.26	1878	2506.26	49.21	08/02/2013

Table 3: Relationship between pH values, time and sampling depths

Depth (mm)	pH/Dates									
	29/11/12	03/12/12	06/12/12	10/12/12	14/01/13	17/01/13	21/01/13	28/01/13	31/01/13	04/02/13
0	7.5	7.3	7.2	7.0	6.9	6.8	6.5	6.5	6.3	6.3
60	7.9	7.8	7.5	7.3	7.1	7.0	6.8	6.8	6.5	6.4
120	7.0	7.0	6.9	6.9	6.7	6.6	6.4	6.2	6.1	6.0
180	6.8	6.6	6.5	6.6	6.5	6.3	6.1	6.1	6.0	5.9
240	6.6	6.6	6.3	6.2	6.2	6.2	6.0	6.0	5.8	5.7

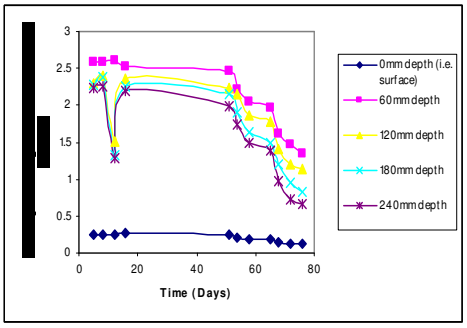

Fig 3: Variation of colony forming units with time and sampling depths

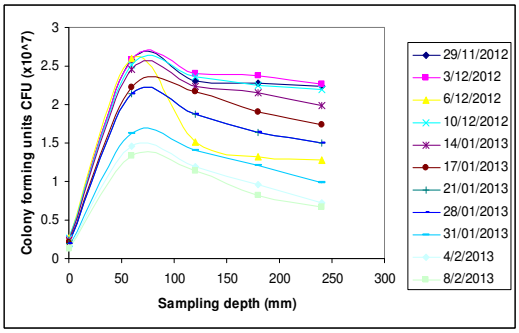

Fig 4: Variation of colony forming units with sampling depths at various dates

3.1 Discussions

In figure 3, faecal Coliform count was minimum at the surface, maximum at 60mm depths and decreased up to another minimum value at 240mm depths. This trend could be as a result of the organisms being in their exponential phase with adequate nutrients and growth conditions at 60mm depth, which later experienced decrease in available nutrients, oxygen and unfavorable growth conditions such as unfavorable temperatures, low moisture content as can be seen in Table 2, decreased pH values shown in Table 3 and water activity. It was also observed that on 29/11/2012, variation of colony forming units/100ml with time was not pronounced at the sludge surface (i.e. 0.0mm depth), on 08/02/2013 maximum value of 0.242×10^7 was experienced while a minimum value of 0.120×10^7 was noticed with a range of 0.122×10^7. Maxima and minima values of CFU/100ml between 29/11/2012 and 08/02/2013 at 60mm, 120mm, 180mm and 240mm respectively were 2.580×10^7 and 1.340×10^7, 2.300×10^7 and 1.140×10^7, 2.280×10^7 and 0.820×10^7, 2.240×10^7, 0.660×10^7. Their ranges are 1.240×10^7, 1.160×10^7, 1.460×10^7 and 1.580×10^7. These findings do not conform with the work of [6] because in their work, the various pathogenic organisms studied were found to survive longer as the sludge initial depth was increased. At the depths of 120mm, 180mm and 240mm, there were sharp decline in the number of CFU/100ml to the 12th day corresponding to06/12/2012 after which the number of colonies increased to the 16th day on 10/12/2012, a trend which is beyond my comprehension and further research is recommended. The trend in figure 3, which depicts both short-term and long-term effect of drying, also indicate that despite the fact that solar radiation destroy pathogenic organisms in sewage sludge, pathogen removal was only significant when moisture content of sludge was drastically reduced. Pathogen die-off rate was consistently increasing from 21/01/2013 to 08/02/2013, a condition which started prevailing when the moisture content of sludge had decreased from 88.99 per cent on 29/11/2012 to 65.48 per cent on 21/10/2013.Another reason for organisms decay in sewage sludge is decrease in nutrients which could be as a result of biodegradation by microorganisms due to competition for food and leaching, as the nutrients are being washed away gradually down the system horizon. Normally, the organic and inorganic nutrients are abundant at the top surface and subsoil regions which correspond to 60mm depth of the drying bed. Despite this scenario, solar radiation tend to inhibit microbial activity and is instrumental to the minimal colony count at the sludge surface, while the influence of solar radiation is insignificant at 60mm depth where the organism experience optimum condition for growth. Temperature of sludge at various depths shown in Table 1 indicate that maximum values occur at 60mm depths throughout the experiments, justifying high microbial activity at this depth and decreased consistently to a minimum value at 240mm depth. This trend is in conformity with Coliform mortality in the system.

In Table 3, it was observed that the pH of the sludge decrease with time, which shows that acidic medium favours pathogen die-off in sewage sludge. It is recommended that conditioners should be used to dewater sludge faster, in order to enhance pathogen die-off since low moisture content does not favour microbial growth in sludge drying beds. Therefore, it is suggested that the top layers of sludge usually 300mm thick has to be scraped off from time to time if bacterial die-off is to be enhanced in sludge drying beds or batch loads should not be more than 60mm thick before dislodging.

4. CONCLUSION

This study has exposed the interacting characteristics of sewage sludge as to how they influence pathogen die-off. Therefore, it is concluded that increased solar radiation, reduced moisture content and acidic medium favor Coliform die-off in sewage sludge drying beds.

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