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Performance evaluation of the UASB sewage treatment plant at James Town (Mudor), Accra

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The UASB Sewage Treatment Plant at James Town, Accra, is used for domestic sewage treatment to remove organic material from the wastewater. To achieve higher removal efficiencies, Trickling Filters, Settling Tanks and other treatment units were used as post treatment. This study analysed the physical, chemical and biological parameters of the influent (raw sewage) as well as the effluent from the plant. The result indicated that the total removal efficiencies were 94.4%, 98.1%, 68.8%, 17.4%, 78.3% and 99.97% for COD, BOD, TS, TKN, PO4-P and Faecal coliform respectively. The overall performance of the plant was generally satisfactory. The study further revealed that Turbidity, Ammonia-nitrogen and Nitrate-nitrogen of the effluents exceeded the EPA guidelines however; the total nitrogen and phosphate-phosphorus of the final effluent could be discharged into the Korle-Lagoon without causing eutrophication or health risk. On the other hand, the current management practices may cause the plant to work inefficiently..

Introduction

Over the years there has been a lack of political will in Ghana to implement basic sanitation and this is reflected in the amount of resources allocated for wastewater management, the main reason being the phenomenal investment in the physical infrastructure of wastewater treatment plants. This coupled with rapid industrialisation and urbanisation have generated increasing amount of wastewater, resulting in environmental deterioration and frequent outbreak of water-borne diseases.

Waste from on-site sanitation systems such as Septic Tanks, Ventilated Improved Pit latrines and Bucket latrines are disposed of in unsightly conditions; thus efficient and cost effective treatment plants are needed to minimize environmental problems and health risks.

Up-flow Anaerobic Sludge Blanket (UASB) reactor as a unit for sewage treatment, under appropriate conditions is quite remarkable. In regions with hot climate a very high removal efficiency of the organic matter (65 to 80%) can be obtained in conventional UASB reactors with short retention time (4 to 6 hours) (van Haandel and Lettinga, 1994 and Campos, 1999). This study therefore seeks to determine the overall performance of the UASB Sewage Treatment Plant at James Town, Accra; with specific objective of assessing the day to day operations and management and to determine the organic, nutrient and pathogenic removal efficiency of the plant. The study began with a review of previous research works carried out on the plant.

The UASB reactor was monitored by measuring the characteristics of the influent and effluents in terms of their COD, BOD, Total Solids, pH, Dissolved Oxygen, Turbidity, Faecal Coliform, Ammonia-Nitrogen, Organic- Nitrogen, Nitrate and Phosphate to assess the overall performance of the plant for eight weeks.

Up-flow Anaerobic Sludge-Blanket (UASB) Reactor

Anaerobic treatment using the UASB-system is one of the promising technologies for application (Lettinga et al., 1993). Effective treatment and some recovery of biogas are achievable with limited maintenance and sludge disposal; however, post-treatment for effective pathogen removal is still required.

In the UASB process, the waste to be treated is introduced in the bottom of the reactor. The wastewater flows upward through a sludge blanket composed of biologically formed granules. Treatment occurs as the wastewater comes in contact with the granules. The gases produced under anaerobic conditions (principally methane and carbon dioxide) cause internal circulation, which helps in the formation and maintenance of the biological granules. The free gas and the particles with the attached gas rise to the top of the reactor.

The particles that rise to the surface strike the bottom of the degassing baffles, which causes the attached gas bubbles to be released. The degassed granules typically drop back to the surface of the sludge blanket. The free gas and the gas released from the granules are captured in the gas collection domes located in the top of the reactor. Liquid containing some residual solids and biological granules passes into a settling chamber, where the residual solids are separated from the liquid. The separated solids fall back through the baffle system to the top of the sludge blanket. To keep the sludge blanket in suspension, up-flow velocities in the range of 0.8 to 1.0m/h should used (Metcalf & Eddy, 2003). However, due to the short liquid retention time in the reactor, the removal of pathogens is only partial. Hence a post treatment unit is required, if the effluent is to be used for irrigation.

Types and Characteristics of Sewage

Faecal sludge
This is the common term used for sludges of variable consistency collected from on-site sanitation systems; via latrines, septic tanks and aqua privies. The collection and transportation of night-soil, septage and toilet sludge from their various sources to the treatment or disposal sites is done by vacuum trucks (or cesspit emptiers). Most often, the contents of the trucks are mixtures of both toilet sludge and seepage; hence it is difficult to distinguish between the wastes that arrive at the treatment/disposal sites.

Night soil
The term night-soil is mostly used to represent a mixture of human faeces and urine (Mara, 1976; Pradt, 1971; Choi et al., 1997). Cairncross and Feachem (1993) stated that night-soil comprises only faeces and urine plus small volumes of water if it is used for anal cleansing and pour-flushing. Sometimes night-soil is also used to represent a mixture of human faeces that has undergone some considerable putrefaction.

Septage
Septage is the sludge produced in individual on-site wastewater-disposal systems, principally septic tanks and cesspools (Metcalf & Eddy, 2003). In water dependent on-site Sanitation facilities, the human excreta are flushed out using water.

Public toilet sludge
This is the term used for sludges collected from unsewered public toilets, which are usually of higher consistency than septage and biochemically less stabilized (Strauss & Montangero, 2001). Doku (1998) referred to the term 'toilet sludge' as night-soil that has undergone little or partial digestion collected from non-water dependent systems.

The James Town Sewage Treatment Works

The wastewater treatment process at James Town Sewage Treatment Works is an integral part of the Accra Waste Project. It is designed and built on sustainable principles including optimised process efficiency for tropical conditions, minimising the consumption of electricity and using appropriate technology. The plant consist of an Anaerobic Primary Treatment Stage, Sludge Thickeners, Aerobic Fixed Growth Reactors (Trickling Filters), Final Settling Tanks and 24 Sludge Drying Beds. The flows from the metropolitan sewered area are discharged from an intercepting sewer into a wet well at the Central Accra Pumping Station (CAPS). The pumping station is about 50m from the UASB reactor which lies approximately 0.5km from the beach, adjacent to the Korle Lagoon located between James Town and Korle Gunno. The sewage is then pumped to the headworks of the UASB Sewage Treatment Plant.The treatment plant is designed to treat a hydraulic flow of 16,120m^3/d – 1000m^3/d from Korle-Bu, 500m^3/d from State House, 1,200m^3/d from Ministries Beach, 1000m^3/d from High Street, 10,380m^3/d from Osu-Labone and 2000m^3/d from Accra Brewery. A coarse screen is provided at the inlet of the wet well at CAPS. Two rotating screens (grit channels) are alternated every two days. The grits are manually removed after the water is drained from it. The grits and screenings end up in a waste chute which is discharged into a skip for disposal. The influent from the grit channel is diverted to primary distribution boxes. The primary distribution boxes ensures an evenly proportion flow to the reactors. Each channel from the primary distribution boxes feed secondary and tertiary distribution boxes. The tertiary distribution boxes connect directly to the down pipes that convey wastewater to the bottom of the UASB reactors. The anaerobic process is maintained within a daily temperature of not more than 29° ± 2. Anaerobic by – products, including methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H2S) are generated. The gas produced from the reactors is collected into gas collector hoods to prevent release of biogas into the atmosphere. The effluent from the UASB reactor flows by gravity to the

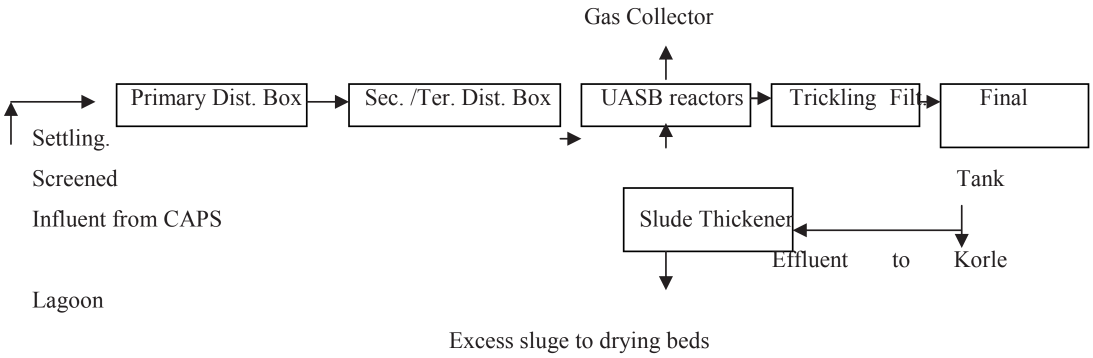

Figure 1. Schematic diagram of Waste Water Treatment Plant

Trickling Filters, where further biological treatment takes place the effluent then flows to the Final Settling Tanks (FST) where fine solids are allowed to settle and further organic reduction is effected using a fine filter screen before the effluent flows to the final sampling chamber. The settled sludge is pumped back into the sludge thickeners. Sludge from the sludge thickeners is discharged to the sludge drying beds where liquid drainage is effected through sand filters and a system of under-drains.

Out of the six UASB reactors at the Sewage Treatment Works only three are in use at a time due the low volume of influent flow.

Qualitative Analysis of Influent and Effluent

The influents and effluents of the UASB reactors were analysed for; pH, Dissolved Oxygen (DO),Turbidity, Chemical Oxygen Demand (COD), Total Solids (TS), Biochemical Oxygen Demand (BOD), Nirate –Nitrogen(NO_3-N), Ammonia-Nitrogen (NH_3 – N), Phosphate-Phosphorus (PO_4- P) and Faccal Coliform (FC).

pH

pH values recorded ranged from 6.26 - 6.99, 7.13 - 10.50, 6.47 - 7.06, 7.36 - 7.74 and 7.29 - 7.66 for the composite of raw sewage, influent flow, effluent from the UASB reactors, the trickling filters and the final settling tanks respectively.

The analysis showed that the pH of the influent were in the alkaline range; this is probably because Accra Brewery Limited uses Sodium Hydroxide to wash the fermentors which could be a major source of high pH thus the alkaline range. Also the pH values for the composite of raw sewage was in the acidic range probably because the hourly samples were stored in a fridge and during that period anaerobic decomposition occurred. Values for effluent from the UASB reactors maintained pH in almost a neutral range because the reactor serves as a buffer system. Values for effluent from the trickling filters and the final settling tanks were in the alkaline range which favours bacteria growth which serves as post treatment of the UASB reactors.

Dissolved Oxygen

Dissolved Oxygen values measured ranged from 0.24 – 0.75mg/l for the composite of raw sewage, 0.19 – 0.80mg/l for influent flow, 0.30 – 0.84mg/l for UASB reactors, 4.61 – 5.60mg/l for trickling filters and 2.54 – 5.66mg/l for the final settling tanks.

The analysis showed that the influent and composite of raw sewage had low concentrations of DO this is probably because the flow was through closed sewer lines. The effluent from the UASB reactor had high concentrations of DO probably because the effluent flows through open channels and at a point in the treatment process discharges from high to a low level, thus absorbing oxygen from the air. The effluent from the trickling filter also had high values because the wastewater trickles through the bed thus absorbs oxygen from the air. The presence of algae in the final settling tank increases the DO levels through photosynthesis, thus the final effluent can be discharged into natural water bodies without causing health implications or eutrophication.

Turbidity and Total Solids

For the turbidity the values had a wide range from 917 – 2374 FAU and 1012 – 2665 FAU for the composite of raw sewage and influent respectively; this is because of the suspended solids in the form of organics and micro organisms in the wastewater. These values were considerably reduced through the various stages however; it did not meet the EPA Ghana guidelines, 2000.

Total Solids values ranged from 1634 – 2674mg/l at the raw sewage influent to 830 – 1080mg/l at the final settling tank effluent. Total removal efficiency from the influent to the final effluent was 68.8%. The relatively lower removal efficiencies across the various treatment stages are attributed to their short retention times.

Chemical Oxygen Demand (COD)

The COD values for composite of raw sewage and the influent flow ranges from 1517 – 2857mg/l and 1630 – 6620mg/l respectively. The wide variance shows that the characteristics of the sewage were widely varied; because UASB reactor is efficient in removing organic material from wastewater, it reduced the COD concentrations to values ranging from 221 – 457mg/l. The removal efficiency of the UASB reactors was 86% slightly higher than the 75 to 85% stated by Metcalf and Eddy, 1995. The final settling tank further reduced the COD concentrations to a range of 110- 175 mg/l thus the total removal efficiency achieved by the treatment plant was 94.4%.

Biochemical Oxygen Demand (BOD)

The analysis revealed that the mean values of BOD were 1206mg/l, 73mg/l, 42mg/l and 23mg/l for the raw sewage, UASB reactors, trickling filters and the final settling tanks effluent respectively. The widely varied values of the raw sewage indicate flow of different characteristics. The low value of the effluent from the final settling tanks is because the UASB reactor drastically reduced the mean BOD values from 1206mg/l to 73mg/l. The removal efficiency of the plant was 98.1%.

Ammonia – Nitrogen (NH_3 – N) and Nitrate-Nitrogen (NO_3 – N)

The raw sewage had a mean value of 4.3mg/l but increased to 19.6mg/l in the UASB reactor. The study revealed that the increase was due to de-nitrification however, the mean value decrease to 2.6mg/l in the subsequent treatment units. The Nitrate – Nitrogen concentrations in the UASB reactors was expected to be zero however, from the analysis it had a mean value of 6.0mg/l which is probably because of dilution prior to the analyses. Nitrification at the subsequent treatment units raised the nitrate concentrations of the final effluent to a mean of 22.1mg/l. These concentrations although exceed EPA maximum recommended guideline for discharge of 1.5 mg/l (EPA, Ghana, 2000), the effluent could be used for irrigation purposes to enrich the soil.

Phosphate – Phosphorus

The average phosphate values measured were 2.31mg/l, 1.03mg/l, 1.47mg/l and 0.50mg/l for the raw sewage, UASB reactors effluent, trickling filters effluent and final settling tanks effluent respectively. The final effluent concentrations meet EPA Ghana, 2000, maximum recommended guidelines of 2mg/l.

Faecal Coliform

Faecal Coliform count ranged from 6.8×10^5 – 1×10^6; 1.4×10^5 – 2.9×10^5; 9×10^4 – 1.4×10^5 and 190 – 245 for the raw sewage, UASB reactors effluent, trickling filters effluent and final settling tanks effluent respectively. The low removal efficiency of the UASB was because of the short retention time however, the post treatment of UASB reactor effluent by the other treatment units, especially, the final settling tanks achieved high removal efficiency. The total removal efficiency recorded was 99.97%.

Management Practices

The UASB reactors are designed to have a liquid retention time of 9 hours. For a good performance and high removal efficiency of COD and BOD, the sludge retention time (sludge age) should be about 60 days. This means that 50 – 60% of the sludge formed in the reactors must be taken out every 60 days. The study revealed that the $40m^3$ of sludge are dislodged every day from the UASB reactor to the sludge thickeners. Also other times $20m^3$ of sludge are taken out in the morning and $20m^3$ in the evening. This practice does not augur well for a UASB reactor because the sludge age is the fundamental parameter which enhances the performance of a UASB reactor for sewage treatment; the longer the sludge age, the greater the number of micro organism in the reactor degrade organic matter and thus increase BOD and COD removal efficiencies.

However, it cannot be concluded that the practice of discharging sludge daily from the reactors is erroneous for the reason that efforts made to have access to design documents proved futile. The study also revealed that there was lack of skilled personnel for example plant engineers, laboratory chemist and plant technicians to see to the day to day operations of the plant.

Conclusion

- The final effluent from the UABS Sewage Treatment met the EPA Ghana, 2000, maximum discharge guidelines, except Turbidity, Ammonia-nitrogen and Nitrate-nitrogen which exceeded the guidelines. Below is a comparison between the final effluent mean values and the EPA Ghana, 2000, maximum discharge guideline values; below is a comparison between the final effluent mean values and the EPA Ghana, 2000, maximum discharge guideline values.
- Discharge of the final effluent from the Sewage Treatment Plant into the Korle-Lagoon may not cause health risks or any major environmental problems;
- The overall performance of the UASB Sewage Treatment Plant was satisfactory. However, the current management practices might cause the plant to operate inefficiently under full operational capacity.

Table 1. Characteristics of sewage at the different treatment stages and comparison of effluent with EPA Ghana 2000, guidelines

Parameter	final influent mean values	UASB reactor effluent	trickling filter effluent	final settling tank effluent	final effluent mean values	total efficiency of the plant (%)	EPA Ghana guidelines, 2000
pH	8.96 ± 0.98	6.7 ± 0.19	7.51 ± 0.13	7.4 ± 0.14	7.45 ± 0.14	-	6-9
Dissolved Oxygen (mg/l)	0.46 ± 0.26	0.58 ± 0.21	5.26 ± 0.32	4.24 ± 1.08	4.24 ± 1.08	-	-
Turbidity (mg/l)	1923 ± 646	265 ± 44	207 ± 52	125 ± 50	122 ± 5e0.27	-	75
Total Solids (mg/l)	3206 ± 2571	1011 ± 130	1038 ± 135	966 ± 94	958 ± 93.78	68.8	-
COD (mg/l)	3173 ± 1528	340 ± 74	310 ± 69	145 ± 21	146 ± 20.62	94.4	250
BOD (mg/l)	1206 ± 397	73 ± 16.2	42 ± 11.4	23 ± 5.7	23 ± 5.74	98.1	50
Ammonia-nitrogen (mg/l)	4.3 ± 1.73	19.6 ± 2.4	7.9 ± 1.4	2.6 ± 0.7	2.6 ± 0.68	39.5	1.5
Nitrate-nitrogen (mg/l)	29 ± 2.82	6.0 ± 1.6	16.6 ± 2.5	22.1 ± 0.83	22.1 ± 0.83	23.8	0.1
TKN (mg/l)	52.6 ± 4.11	93.1 ± 6.5	60.7 ± 2.25	43.1 ± 1.2	43.1 ± 1.15	17.4	-
Phosphate-phosphorus (mg/l)	2.31 ± 0.14	1.03 ± 0.17	1.47 ± 0.53	0.5 ± 0.14	0.5 ± 0.14	78.3	2
Faecal coliform (no./100ml)	$9.2 \times 10^5 \pm 1.1 \times 10^5$	$2.0 \times 10^5 \pm 4.9 \times 10^4$	$1.2 \times 10^5 \pm 1.8 \times 10^4$	$2.15 \times 10^2 \pm$ 16.31	$2.16 \times 10^2 \pm$ 16.31	99.9	10-100

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