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Design of Modern Wastewater Treatment Plant for the University of Port Harcourt

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***Abstract*— A design of wastewater treatment plant for University of Port Harcourt was carried out. The detailed computation of the parameters needed for proper design of a modern wastewater treatment plant was evaluated for the University of Port Harcourt. The incremental method was used to estimate the population of the University in fifty years' time which was observed to be 141,742. The wastewater sample from the sewage vacuum truck was tested in the laboratory for BOD_5 and TSS which gave an average of 280mg/l and 584mg/l respectively. The volume of water supplied to the University was estimated to be 800l, with an average and maximum flow rate of $0.343m^3/s$ and $0.740m^3/s$ respectively. With the application of a completely mixed activated sludge system, the results indicated that treated wastewater had a BOD_5 and TSS reduced to 14mg/l and 29.2mg/l respectively. The amount of sludge generated from the primary treatment was 4137kg/d and the secondary treatment was 2342.96kg/d. The research is significant because it showed the possibility of establishing a wastewater treatment plant in preference to septic sewage tank in the University of Port Harcourt**

***Index Terms*—About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

Water is one of the abundant gifts of nature and finds great importance to man and his environment. Due to the technical and agricultural activities of man, he therefore depends on water which he can get from lakes, rivers, and groundwater supplies (Howard et al., 1985).

Once water has been put to use such that it losses value and can no longer meet its original requirement, it is then classified wastewater. According to Steel and Terence (1979), "wastewater is the combination of liquid wastes obtained from residential buildings, commercial buildings and institutions and from industries".

Chatterjee (2011) described wastewater as a combination of sewage and sullage from a municipal, kitchen and wash basins which can be managed through collection, treatment and proper disposal. (Mackenzie and David, 2013). In countries, where the scarcity of water is prevalent, wastewater is considered as a raw material and it is been recycled for reuse. The scope of the study was to design, compute necessary parameters required to treat only sewage generated from the three campuses of the University of Port-Harcourt. The study assumed that the generated sewage will be channeled down to the wastewater treatment plant through a network of pipes interconnected underground which served as the carriage systems.

The design was an embodiment of unit operation and set up to reduce certain constituents of wastewater to a permissible level (Howard et al., 1985). Over the years, the use of the septic system as a treatment facility has been the practice of the University of Port Harcourt in managing its sewage. The septic system is old, fast becoming obsolete in many advanced cities, occupies useful land spaces, generate offensive odor particularly when filled and puts the ground water quality at risk thereby pose danger to environmental health (Philliard, 2014) hence the need for this study.

This research proposes a wastewater treatment plant that employ the preliminary treatment, primary treatment and secondary treatment (activated sludge) processes in the plant.

II. METHODOLOGY

2.1 Study Area

The study area (see Fig. 1) covered the three campuses (Abuja, Delta and Choba park) of the University of Port Harcourt.

2.2 Proposed Location for WWTP

Site investigation was done using Google map, which aided the choice of Abuja campus with the largest land coverage of about $7.0km^2$, as the suitable location for the establishment of the WWTP. Abuja campus also provided suitable land for the disposal of the treated wastewater.

2.3 Data Collection

During the study, the population data and the wastewater samples were collected. The population of the students on campus, academic staffs and the non-academic staffs was obtained from the physical planning office of the University while the waste water samples were obtained directly from the sewage vacuum truck in a container covered with a black nylon in order to reduce the effect of the environment on the samples. The pH of each sample was determined immediately using the digital pen pH meter. The waste water samples were taken to the laboratory for proper analysis of BOD, TSS, MLSS and MLVSS using standard methods.

2.4 Flow Analysis and Discharge Standards:

The proposed design layout showed that waste water flows from University campuses into the preliminary section with bar screen and the aerated grit chamber to the primary section (the primary clarifier), then the secondary section (the secondary clarifier), and finally disposal in the form of solid dry sludge or treated wastewater to sewage farm. (Figure 2)

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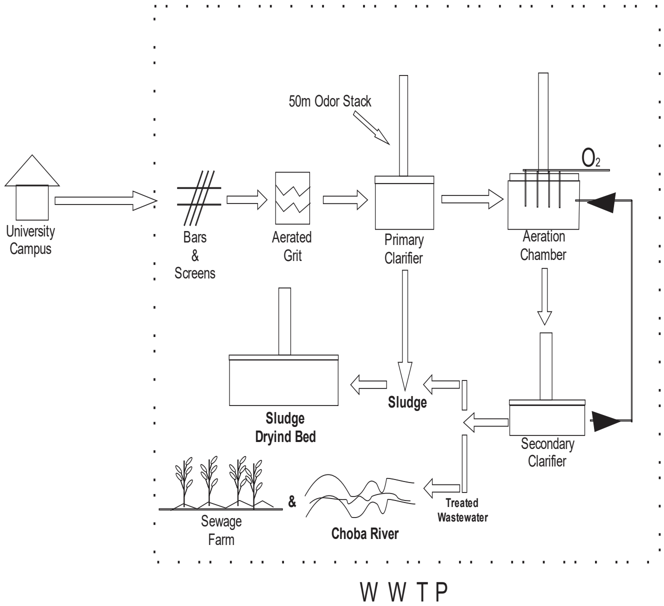

Fig 2: Diagrammatic view of the flow of wastewater

The study ensured that the UNESCO effluent standards (Table 1) served as a guide.

Table 1: UNESCO Discharge Standards

Parameters	Concentration (mg/l)	Minimum Percentage of Reduction (%)
Biological Oxygen Demand, BOD_5	25	70-90
Chemical Oxygen Demand, COD	125	75
Total Suspended Solids, TSS	35	90

Source: (Chen Jining and Chu Junying, 2011)

2.4 Odor Control:

The study considered use of Hydrogen peroxide applied at specified dose to influent in preference of Chlorine due it Chorine environmental impact to eliminate odor in the waste water treatment plant (Water-Technology, 2015). The primary, secondary, and aeration tank; and the drying bed shall be installed 50m stack to collect, treat and vend odorous gases like hydrogen sulphide due to the activities of decomposing bacteria far from ground level.

2.5 Design Assumptions:

The study assumed that:

1. Design period to be 50 years
2. The period of study of each department as 5years
3. Every academic session from 2016/2017 to 2067/2068 was one-tenth decade
4. The population of staffs in the University was constant for all years.
5. The population of students admitted is on the increase per session
6. The optimum flow of wastewater every day was suitable for the treatment processes.
7. 80% of water used returns as wastewater.
8. The effect of precipitation on the treatment and amount of wastewater was negligible.
9. Separate sewer system was used in collection and transfer of wastewater.
10. Sewer operation was under gravity to minimize cost.
11. Amount of water supplied to resident was 600l/d while to non-resident was 200l/d making a total of 800l/d
12. The sewage or wastewater used was assumed to be fresh

2.6 Population Forecast

The population forecasting was made possible using the incremental method expressed in the equation (1) to give the incremental trend:

$$P_x = P + n(a + b) \qquad (1)$$

Where, P_x = the population of the future year; X = the year; P = the population of the last year

n = number of decades, (in this case, one-tenth decade); a = average increase; b = average incremental increase

The equation (2) was employed to get the total population of students on campus

$$P_{YEARTOTAL} = P_{YEAR\,1} + P_{YEAR\,2} + P_{YEAR\,3} + P_{YEAR\,4} + P_{YEAR\,5} \qquad (2)$$

$P_{YEARTOTAL}$ = total population of students on campus

$P_{YEAR\,1}$= student population in the year before the year under consideration

$P_{YEAR\,2}$=student population in two years before the year under consideration

$P_{YEAR\,3}$=student population in three years before the year under consideration

$P_{YEAR\,4}$=student population in four years before the year under consideration

$P_{YEAR\,5}$=student population in five years before the year under consideration

The results were shown in Table 3.

2.7 Flow Rate Computation

The average flow rate per head was obtained using the equation 3.

$$Q_{av} = \frac{\text{amount of water supplied} \times \text{popularion}}{1000 \times 86400} \qquad (3)$$

where, Q_{av} = average flow rate, in m^3/s

The equation 4 gave the relationship between maximum and average flow rate (Fair and Geyer, 1954).

$$Q = \frac{Q_{max}}{Q_{av}} = \frac{18 + \sqrt{P}}{4 + \sqrt{P}} \qquad (4)$$

where, Q = ratio between maximum and average flow rate; Q_{max} = maximum flow rate in m^3/s

Q_{av} = average flow rate in m^3/s; P = population in thousands

2.8 Bar Screen Design Criteria

Applying Chatterjee (2011) criteria for maximum velocity (0.6m/s); approach velocity (0.3m/s); Acceleration due to gravity (9.81m/s^2); bar spacing (25m); Depth of flow (1.5m) and coefficient of discharge (0.6); equation 5 was used to estimate the Head loss (H_L) of the bar screen

$$H_L = \frac{1}{C_d}\left(\frac{V_s^2 - v^2}{2g}\right) \qquad (5)$$

where, V_s= flow velocity in m/s; v= approach velocity, taken as 0.3m/s; C_d= coefficient of discharge, 0.70 – 0.84 for clean screen and 0.6 for clogged screen

2.9 Design Criteria for Aerated Grit Chamber

Applying Metcalf and Eddy (1995) design criteria for peak condition using two independent chambers; detention time was (4mins); depth of each chamber (4.5m); width: depth (1:1); length: width (4:1); grit quantities ($0.10m^3/1000m^3$) and air supply ($0.35m^3$/min per meter).

2.10 Design Criteria for Sedimentation Tank

For Primary Sedimentation tanks: six rectangular tanks were used; BOD_5 removal efficiency (50%); Overflow rate ($35m^3/m^2.d$); length: width (4:1) and free board (0.4m). For secondary sedimentation tank: six circular tanks were employed with overflow rate ($15m^3/m^2.d$) and depth of clarifier taken as 4m (Chatterjee, 2011).

2.11 Design Criteria for Aeration Chamber

The design considered completely mixed activated sludge system with BOD_5 removal efficiency (90%), Number of aeration basin (6); Mean cell residence time (10d); mixed liquor suspended solids (3000mg/l); soluble effluent BOD (6.0mg/l); water depth (4m); Recycle ratio (0.625); waste sludge ratio (0.01); length: width (2:1) and freeboard (0.4) (Howard et al., 1985).
From William and Lisa, (2001), the microbial parameters include K_d and Y which were $0.06d^{-1}$ and 0.6 respectively. Also, the specific gravity of air was taken as $1.185kg/m^3$ with 21% Oxygen value.
The equations 6, 7, 8, and 9 were used to obtain the volume of the aeration basin, biological sludge growth, recycled wastewater flow rate and oxygen demand respectively

$$V = \frac{QQ_cY(S_o - S)}{X(1 + kdQ_c)} \quad (6)$$

$$\frac{\Delta X}{\Delta t} = \frac{XV}{Q_c} \quad (7)$$

$$Q_rX_r = (Q + Q_r)X \quad (8)$$

$$O_2 demand = 1.47(S_o - S)Q - 1.44X_rQ_w \quad (9)$$

where, V = Volume of aeration basin, m^3; Q_c = Mean cell residence time, day; Q = Influent wastewater flow rate, m3/d; Y = Yields coefficient over finite period of log growth, g/g; S_o = Influent soluble BOD_5 concentration, mg/l; S = Effluent soluble BOD_5 concentration, mg/l;
X = Concentration of MLVSS, mg/l; k_d = Endogenous decay coefficient, d^{-1}; $\frac{\Delta X}{\Delta t}$ = Growth of biological sludge over time period, kg/d; Q_r = Recycled wastewater flow rate, m^3/d; X_r = Returned sludge concentration, mg/l, and Q_w = Aeration tank sludge flow rate, m^3/d
$O_2 demand$ was the demand of oxygen by the bacteria in kg/d

2.12 Drying Bed

Sand drying beds were provided in a number of six. The depth of sludge on the bed was 25cm and the length, 30m (Fatima, 2011).

2.13 Sludge generated

The amount and volume of sludge generated from the primary sedimentation tank and the aeration basin were computed as shown in equations 10, 11, 12, 13 and 14:
For primary clarifier

$$Z = I \times \eta \times Q_{av} \quad (10)$$

$$V_s = \frac{z}{\gamma \times \eta} \quad (11)$$

For aeration basin

$$Y_{obs} = \frac{Y}{(1 + \frac{K_d}{2Q_{av}})} \quad (12)$$

$$P = Y_{obs} \times Q(S_o - S) \quad (13)$$

$$V_s = \frac{P}{\gamma \times \eta} \quad (14)$$

where, Z_p = The amount of sludge generated from the primary clarifier (kg/d);
V_s =Volume of sludge (m^3/d); Y_{obs} =Observed yield from aeration basin (g/g)
P =Amount of sludge generated from the aeration basin (kg/d); S_o = Influent soluble BOD in mg/l; S = Effluent soluble BOD in mg/l

III. RESULTS

The design parameters for the operational units of the treatment plant were presented in Table 4 – 12.

Table 2: Laboratory Results

Samples	pH	TSS (mg/l)	MLSS (mg/l)	MLVSS (mg/l)	BOD_5(mg/l)
Delta Campus w/w	5.08	574	2382	427	310
Abuja Campus w/w	5.16	528	2150	388	250
Choba Campus w/w	6.13	650	1948	418	280
Average	5.46	584	2160	411	280

Table 3: Population forecast

Year	2017	2018	2019	2065	2066	2067
Total population for students	47925	51159	54721	138051	139897	141742

Table 4: Flow rate requirements

Parameters	Total Water Supply (litres)	Average flow rate (m^3/s)	Maximum flow rate (m^3/s)
Value	800	0.343	0.740

Table 5: Screen design parameters

Parameters	Bar Spacing (m)	Depth (m)	Clear area, (m^2)	Width of mesh (m)	No. of bar spacing	No. of bars	Width of chamber (m)	Screen efficiency (%)	Head loss (m)
Value	0.025	1.500	0.570	0.380	16	15	0.530	71	0.023

Table 6: Aerated grit design parameters

Parameters	Detention time, mins	Depth (m)	Q_{max} (m^3/s)	Width (m)	Length. m	Air require (m^3/min)
Value	4	4.50	0.37	4.50	18	6.30

Table 7: Design parameters for primary sedimentation tank

Parameters	Influent BOD_5 (mg/l)	Influent TSS (mg/l)	Average flow, (m^3/s)	Max. flow, (m^3/s)	Area (m^2)
Value	280	584	0.057	0.12	140.70

Parameters	Length (m)	Width (m)	Depth (m)	Volume (m^3)	Detention time at Q_{av}(h)	Detention time at Q_{max} (h)
Value	23.60	5.90	3.90	487.34	2.37	1.13

Table 8: Aeration chamber design parameters

Parameters	MLVSS, X (mg/l)	Influent BOD, mg/l	Influent TSS, mg/l	Volume (reactor) (m^3)	Area of basin (m^2)	Width of basin (m)	Depth of basin (m)
Value	427	140	292	827.3	206.80	10.20	4.40

Parameters	Detention time (h)	Sludge growth (kg/d)	Q_w, (m^3/d)	Q_r (m^3/d)	X_r (mg/l)	O_2 demand (kg/d)	Air required (m^3/min)
Value	4.02	1489.17	49.40	3087	31800	4917.96	13.70

Table 9: Secondary clarifier design parameters

Parameters	Basin flow rate (m^3/s)	Area (m^2)	Diameter (m)	Volume of basin (m^3)	Detention time at average flow (h)	Detention time at max. flow (h)
Value	0.09	518.40	25.69	1814.20	5.59	2.64

Table 10: Amount of Sludge generated from the primary clarifier

Parameters	Specific gravity (g/cm^3)	Moisture content (%)	Amount of sludge (kg/d)	Solid content of sludge (%)	Volume of sludge (m^3/d)
Value	1.03	95	4137	5	80.3

Table 11: Amount of Sludge generated from the Aeration basin

Parameters	Observed yield (g/g)	Amount of sludge (kg/d)	Volume of sludge (m^3/d)
Value	0.59	2342.96	45.49

Table 12: Dry bed design parameters

Parameters	Area for each bed (m^2)	Width for each (m)
Value	83.90	2.80

DISCUSSION

Table 2,s showed that the concentration of the wastewater in Delta campus and Abuja campus were acidic in nature. The concentration of the wastewater in Choba campus is slightly neutral. The BOD_5 of the wastewater from each of the campus revealed that the wastewater from Delta campus was more toxic to the aquatic life. The average value for each parameter analyzed in the laboratory was used for computation.

The population data obtained from the University for the past 10 years showed a consistent increase in the population of the student while that of staff remained constant. From Table (3), Equation (1) and (2) was used to obtain the population of the future year, the result showed a linear growth in population which gave 141742 as the population in 2067. The result can be regarded as a supposition in case the University population growth is not put into check as the case is.

The total amount of water supplied to the University was a combination of the water supplied to the population residing on campus and the population not residing on campus. Using Equation 3 and 4, the average and maximum flow rate was obtained.

The design considered a 71% screen efficiency and a head loss of 0.023m, and assumed that mechanical parts of the plant were protected from damage to be caused by solid particles in the wastewater.

Two aerated grit chamber were provided according to results in Table 6, because there need to be a substantial reduction in the BOD_5 and TSS level of the wastewater before secondary treatment occurs. When a chamber fails, the other chamber can continue the process as maintenance takes place.

Table 7, showed design criteria for 6 nos. primary sedimentation tank. This will result to a faster and effective reduction in the toxicity level of the wastewater as detention time for treatment were 2.37h and 1.13h at average and maximum flow respectively. If maintenance is ongoing in one tank, the sedimentation process remains unhindered.
Table 8, showed criteria for six chambers required for the completely mixed activated sludge process. The average result for the MLSS was 85 to 95%. The influent BOD dropped to 140mg/l while the influent TSS dropped to 292mg/l as a result of the primary treatment. This means that a 50% reduction in toxicity level of the wastewater was achieved during the primary treatment. About 5000kg of oxygen was required per day to achieve high BOD_5 of the wastewater and 90% reduction in toxicity.

Table 9 showed that the volume of the secondary sedimentation tank was twice volume of primary sedimentation tank because the final treatment of the wastewater occurs here and the treated water was detained for a longer time. The detention times at both average and maximum flow were twice as much as that in the primary sedimentation tank.

Table 10 & 11 shows that the amount of sludge generated from the primary clarifier was large due to excess solid materials undergoing sedimentation

Table 12 indicated that six beds were provided for the drying of the sludge. When one bed is full and undergoing maintenance, the process remains unhindered.

CONCLUSION

The design study estimated and computed necessary parameters to establish a wastewater treatment plant at the pride of the University of Port Harcourt. The total area of land covered by the WWTP devices and reactors was approximated about 1% of the land coverage of Abuja campus.The showed that the wastewater generated the University campuses can be treated to meet the UNESCO discharge standards with the combination of preliminary, primary and secondary treatment facility and disposed. Table 1 showed that BOD_5 and TSS were reduced to 14mg/l and 29.2mg/l respectively. With sewage flow in network of pipes to the sewage treatment system, the use of vacuum truck was eliminated. Also, the sewage odour perceived with the school environment will no longer be an issue if the sewage waste water design is implemented.

RECOMMENDATIONS

The study recommended that the treated wastewater be used in the University toilets as flush water, for recreational activities and non-body contact activities. The treated wastewater can also be spread over lands (that is, sewage farms) for percolation and evaporation to take place.

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