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Conceptual Design of a Decentralized Wastewater Treatment System for the Bamenda Regional Hospital, Cameroon

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Abstract

The Bamenda Regional Hospital, like most hospitals in Cameroon, lacks an appropriate wastewater treatment system. The main objective of this work was to evaluate the state of the existing sanitation infrastructures in the Bamenda Regional Hospital and design a decentralized wastewater treatment system for the Hospital. The research methodology involved pre-research preparations, field data collection via semi-direct interviews with officials of the hospital, field observations and data analysis. Results obtained from semi-direct interviews and field observations revealed that the existing sanitation infrastructures in the hospital are inappropriate for the treatment of the hospital's wastewaters due to their deteriorating state and poor design. We therefore designed in this paper a decentralized wastewater treatment system made up of a sewer network constituted of 12 main PVC pipes (S1, S2, S3, S4, S5, S6, S7, S8, PS, PS1, PS2 and PS3) and four treatment units: a settling tank (volume=13.25 m^3, area=3.68 m^2, depth=3.60 m, width=1.84 m and length=2.00 m); two 6-chambered anaerobic baffled reactors placed in series (each having a working volume of 317.95 m^3, compartment up-flow area of 22.08 m^2, total compartment area of 29.44 m^2, reactor depth of 3.00 m, reactor width of 7.28 m and a reactor length of 14.56 m) ; two 3-chambered anaerobic filters placed in series (each having volume of filter of 66.24 m^3, volume of packed bed of 41.4 m^3, area of 27.6 m^2, depth of 2.40 m, width of 5.25 m and a length of 5.25 m); and a horizontal planted gravel bed (with a cross-sectional area of 8.83 m^2, total length of 7.00 m, width of 1.26 m, height of 1.5 m and 36 plants). A pump with an effective power of 0.03 KW was also designed. The choice of the system proposed in this work was governed by the fact that: the cost of construction, operation and maintenance of the different treatment units is relatively low compared to other technologies; the construction materials are locally available; the system does not require large area since the units are constructed underground; the system energy requirement is very low or almost zero; reports from researchers reveal that the different units combined in the chosen system have individually shown good treatment efficiencies.

Introduction

Hospitals generate large quantities of wastewaters i.e. on average 750 L of wastewater by bed per day with 250-350 L for hospitalization and technical services, and 350-450 L for general services. These wastewaters contain antibiotics (particularly sulfonamides and fluoroquinones which are generally found at relatively high concentrations in hospital wastewaters [1], x-ray contrast agents (such as diatrrzoate, iopromide and iopamidols), disinfectants, heavy metals (cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc), pharmaceuticals and substances with genotoxic and cytotoxic activity and enteric pathogens [2,3]. Hospital wastewater also contains several organic substances that are resistant to biodegradation with low biodegradability ratios of usually 0.3 [4]. In Cameroon, no national inventory on wastewater disposal from hospitals exists. However, a report published by the Cameroon Ministry of Water Resources and Energy in 2011 revealed that from inventories carried out in Yaounde in 2002, it is possible to classify hospitals under three (03) categories as per function as referral hospitals, regional hospitals and other health centers. This same inventory carried out in Yaounde estimated the monthly production of hospital wastewaters to be 25000 m^3. This production is more important in Douala and lesser in the other towns. Of the 2474 public health formations in Cameroon, only one (the CNPS hospital) possesses a functional wastewater treatment plant (No data, however, exists on the microbiological treatment efficiency of this plant [5]. This implies that just like the domestic wastewaters, wastewaters from hospitals in Cameroon are drained by specialized trucks from septic tanks and disposed directly into some poorly maintained dumpsites at Nomayos in Yaounde and "Bois des Singes" in Douala.

The Bamenda Regional Hospital, like the other hospitals in Cameroon, lacks a wastewater treatment system. Due to the high level of pollution and toxicity of pharmaceutical wastewaters which can pose a real risk to the environment and the health of populations, the question of their proper management before disposal into the environment is a reality nowadays. This management goes from their effective treatment via adequate treatment facilities before their disposal to nature. According to the World Bank, the greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes [6]. In this paper, we present an evaluation of the state of the existing sanitation facilities of the Bamenda regional hospital. We also designed a decentralized wastewater treatment system for the treatment of the hospital's wastewaters.

Presentation of the Bamenda Regional Hospital

The Bamenda Regional Hospital contains 240 beds with a patient

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turnover of more than a thousand monthly. The hospital uses the services of 220 trained government staffs made up of doctors, nurses, laboratory technicians and support staffs. It is divided into departments amongst which we find the: Administrative, statistic, surgical, medical, dental, gynecological, pediatrician, technical (medical laboratory) and infection control departments. Added to this, it also features a kitchen, pharmacy and mortuary service. Besides these departments, we also have wards amongst which we can distinguish the general, maternity and surgical wards.

The sanitation facilities of the hospital is made up of just the classical user interface (flush toilets) and collection/pre-treatment unit (septic tanks) some of which are connected to soak pits. The user interface is made up of pour flush toilets and cistern flush toilets. The cistern flush toilets are usually reserved for the patients of the VIP wards, while the other patients and the hospital's population as a whole use the pour flush toilets. The collection/pre-treatment units consist of numerous septic tanks of different dimensions which receive wastewaters from the toilets, restaurant, laboratories and mortuary. These wastewaters are transported to septic tanks via PVC sewers of different sizes. These septic tanks are connected to soak pits via which the wastewaters are directly drained into the soil. Field reports from the hygiene and sanitation service of the hospital revealed that the septic tanks haven't been drained for decades now.

The technology used for the user interface is inappropriate as the toilets are old and out of use. The pour flush toilet technology is not appropriate for hospitals. This is because it is a technology difficult to be used by very sick or ill persons as it demands that one should bend down before using it. Moreover, some of the toilets are located at very far distances from some patient wards and services making their access very difficult to patients. Added to this is the dirty aspect of the toilets. The septic tanks used in the hospital were designed and constructed decades back and today cannot support the present volume of wastewater produced, thus leading to their over load and the eventual flow of wastewater in the surrounding environment. This presents a real health risk to the hospital population as well as a risk of soil and ground water pollution. The poor positioning of some of the tanks exposes the hospital population to bad odors.

The sewer network used to connect the user interface to the septic tanks and some of the septic tanks to soak pits is made up of old and worn out pipes, some of which contain leakages, leading to the flow of wastewater into the environment. In some areas, the pipes connect the septic tanks into soak pits. Reports from the field revealed that no geotechnical or water bed level testing research was done before the use of the soak pit technology. This presents a high risk of soil and underground water pollution as the infiltrated wastewater can come in contact with the water bed in case the latter is high. Moreover, just like the septic tanks, some of the soak pits are located in non-appropriate positions in the hospital with some directly found in front of patient wards and technical services.

Research Methodology

This research work was carried out in the Bamenda Regional Hospital located in Bamenda, the Regional Capital of the North West Region of Cameroon.

Research phases

This study was conducted using pre-research preparations, semi-structured interviews and field observations and data collection, data analysis and mathematical calculations.

Pre-research preparation

Prior to the different works on the field, a series of pre-research preparations was made. The main objective of this phase was to get acquainted with the research topic and clearly define the research objectives. During this phase, the various tools needed for the study were determined and elaborated. It was also in this phase that preliminary searches on the internet relating to the topic were carried out.

Semi-structured interviews

After the pre-research phase, semi-structured interviews were carried in two phases. The first phase was done before documentary analysis and the second after documentary analysis and field observations. The main objective of the first phase of the semi-structured interview was to obtain the first contact with the officials concerned with the administrative coordination and management of the Bamenda regional hospital. During this phase, interviews were granted to: the director of the Bamenda regional hospital, the staffs of the statistic unit of the hospital and the staffs of the hygiene and sanitation service of the hospital. They were aimed at obtaining information relating to the: different services of the hospital, number of beds, total receiving capacity of the hospital, various departments capable of producing wastewaters, estimated daily consumption of water in the hospital, estimated daily wastewater production, and the management of the hospital's wastewaters.

On its part, the second phase of the semi-structured interviews was done after field observations and data collections were carried out. The objective of these secondary semi-structured interviews was to get the opinions of the different officials on the sanitation and wastewater treatment situation of the hospital. These interviews were much more technical as it was done after field observations which permitted us to have a precised idea and knowledge on the situation in the hospital. The research tool used for all the interviews was the grid for semi-structured interviews.

Field observations and field data collection

This phase was carried out after the semi-direct interviews. Field observations and data collection were of capital importance to this study as it gave the opportunity to compare information collected during the semi-structured interviews with the reality on the field. During this phase all the services and sanitation infrastructures of the hospital were overviewed. Records of their state, functionality and efficiency were reported on the grid for participatory observation. These observations were accompanied by field photographs.

Data analysis and mathematical observations

After the observations and data collection, the information recorded during the documentary analysis, the field works and the second semi-direct interviews were simultaneously used in data analysis. The various treatment units were designed using mathematical calculations via Microsoft excel.

Design methods for the wastewater treatment system

In this work, the wastewater treatment system proposed is one made-up of a sewerage (made up of sewers) network that collects wastewaters from the user's interface (toilets, restaurant and other collection units) to the treatment unit which is constituted of: a settler or settling tank; 02 anaerobic baffled reactors; 02 anaerobic filters; a pumping station; a horizontal planted gravel bed. The flow chart of wastewater flow via the proposed wastewater treatment system for the Bamenda Regional Hospital is given below (Figure 1).

The wastewater from the various units of the hospital shall be conveyed via sewers S1-S8 to sewers PS (Figure 2). The latter shall convey the wastewater into the first unit of the treatment system, the settling tank. In the settling tank, primary treatment of the wastewater takes place. Here suspended solids are removed be sedimentation or flotation. Also referred to as sedimentation or settling basin/tank, or clarifier, the low flow velocity in a settler allows settle able particles to sink to the bottom, while constituents lighter than water float to the surface [7].

The pre-treated water leaving the settling tank enters the first and then the second anaerobic baffled reactor placed in series. The anaerobic baffled reactor (ABR) is a high rate anaerobic digester that is internally compartmentalized by a series of hanging and standing baffles. Wastewater enters the reactor and flows under a natural head under and over the hanging and standing baffles. No oxygen or mechanical mixing is applied in the ABR; treatment is achieved by anaerobic digestion by naturally selected anaerobic microbial consortia (referred to as sludge) (Figure 3). The ABR is similar in concept to a septic tank in that passive treatment of wastewater is obtained by the (relatively) unassisted development of anaerobic micro-organism consortia in a simple digester design [8].

From the second ABR, the wastewater continues its treatment as it flows into the first anaerobic filter and then to the second also placed in series. An anaerobic filter is a fixed-bed biological reactor with one or more filtration chambers in series. As the wastewater flows through the filter, particles are trapped and organic matter is degraded by the active biomass that is attached to the surface of the filter material or packing medium.

The semi-treated wastewater leaving the second anaerobic filter shall be conveyed in to the horizontal planted gravel bed where, it shall undergo final treatment. The horizontal planted gravel bed designed in this work combined the horizontal-flow roughing filtration technology

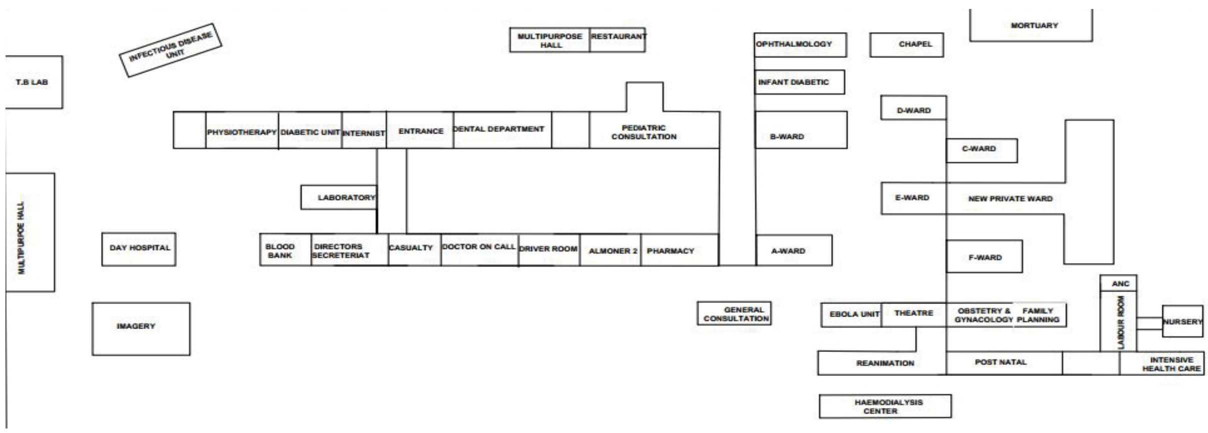

Figure 1: Diagrammatic representation of the Bamenda Regional Hospital showing the various departments.

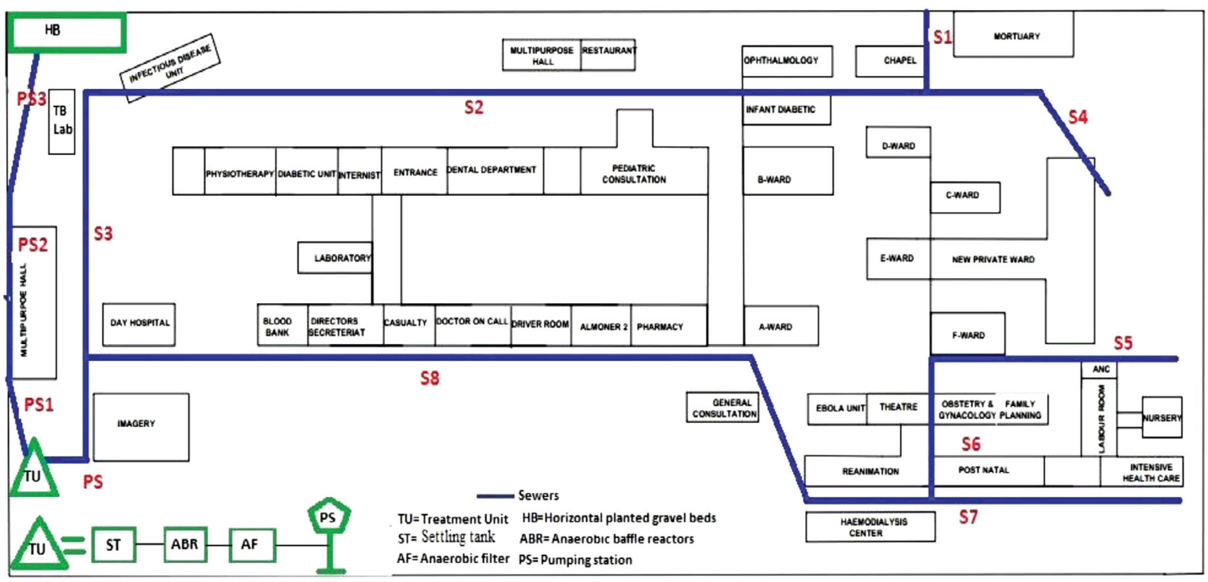

Figure 2: Lay-out of the proposed decentralized wastewater treatment system showing the sewer network and treatment units.

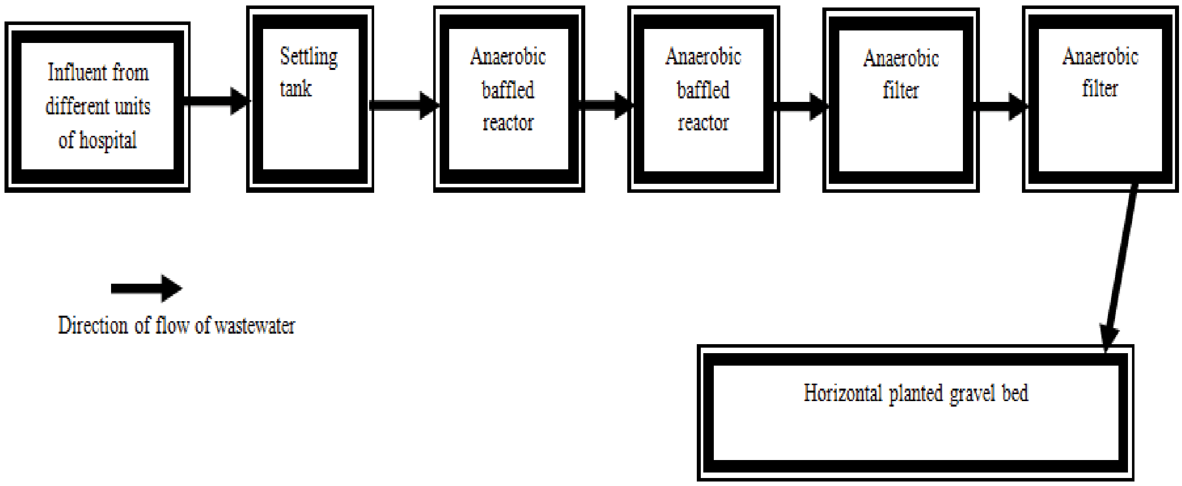

Figure 3: Flow chart showing the direction of flow of wastewaters from the different units of the hospital through the various units of the proposed decentralized wastewater treatment system.

and planted reeds. The main characteristics of the process are its horizontal flow direction and the graduation of the filter material. The wastewater flows horizontally and the pollutants still contained in the influent are filter via the filter bed (made up of three layers), while the ventilation pipes are also used to supply oxygen for plant roots, which enhances the treatment.

Design Principles and Mathematical Calculations

Design of sewers

To design the sewers, we principally determined the wastewater flow rate (Q) in the sewers, the diameter of the sewers (D) and the velocity of wastewater in the sewers (V).

- The flow rate was determined by the equation:

Where:

$$Q_{wastewater} = Q_{aqueduct} * \phi = DNP_d P_h \phi \quad (1)$$

D: water consumed per hospitalized patients, per caregiver, as well as the daily permanent hospital staffs.

N: number of hospitalized patients, caregivers, as well as the daily permanent hospital staffs.

P_d: daily peak coefficient. It takes into account the daily water consumption. 1.20< Pd <1.50

P_h: hours peak coefficient. It takes into account the hourly consumption. 1.20< Ph<1.50

ϕ: It takes into account the losses, the amount of water that does not end in the sewer. ϕ is generally between 0.8-0.9.

The diameter of the sewers was determined going from the Strickler's equation whereby:

$$D = \left(Q / 0.312 * K_s * J^{1/2}\right)^{3/8} \quad (2)$$

Q: wastewater flowrate (m^3/s)

J: corresponding slope

K_s: Strickler's coefficient

The final value for each sewer diameter shall be the nominal diameter for each calculated diameter. The K_s used was that of PVC= $95m^{1/3}/s$.

The velocity of wastewater in the sewers was determined going from the equation

$$V = Q \;/\; \left(\prod * D^2 / 4\right) \quad (3)$$

V: velocity in sewer (m/s)

Q: wastewater flowrate (m^3/s)

D: diameter of the sewer (m)

Design of the settler

The design parameters taken into account were the: hydraulic retention time (HRT), volume of the basin, surface area of the basin and the surface loading rate.

Several calculated experimental values exist for the HRT for settling tanks. The value considered in the course of this work was 2h.

The volume of the settler was determined using the equation:

$$V = Q * HRT \quad (4)$$

V: volume of tank (m^3)

Q: influent flowrate in (m^3/h)

HRT: hydraulic retention time (h)

The surface loading rate (v) was determined using existing calculated experimental values. In this work, the value of v considered was 1.8 m/h.

The surface area of the settler was determined using the equation:

$$A = Q / v \quad (5)$$

A: surface area of settler (m^2)

Q: influent flowrate (m^3/h)

v: surface loading rate (m/h)

The depth of the settler was determined using the equation

$$H = V / A \tag{6}$$

H: depth of settling tank (m)

V: volume of tank (m^3)

A: surface area of tank (m^2)

Design of the anaerobic baffled reactors (ABR)

In this work 02 six-chambered anaerobic baffled reactors were designed by methods described by Foxon and Buckley. The design parameters that were taken into consideration are: design hydraulic retention time, number of compartments, peak up-flow velocity, compartment width to length ratio, reactor depth and compartment up-flow to down-flow area ratio.

The hydraulic retention time (HRT) was determined using existing calculated experimental values. In this work, the value of HRT considered for each reactor was 48h.

The working volume of the reactors was determined by the equation:

$$V_w = Q * HRT / 24 \tag{7}$$

V_w: working volume of reactor (m^3)

Q: influent flowrate in (m^3/d)

HRT: hydraulic retention time (h)

The up-flow velocity (V_d) in each reactor was determined by the expression:

$$V_d = V_p / 1.8 \tag{8}$$

V_d: designed up-flow velocity (m/h)

V_p: peak up-flow velocity (m/h)

The value of V_p was determined from existing calculated experimental values. In this work we use as V_p 0.54 m/h. On its part, the 1.8 represents the peak flow factor.

The compartment up-flow area (A_u) for each reactor was determined by the equation:

$$A_u = Q / (V_d * 24) \tag{9}$$

A_u: compartment up-flow area (m^2)

Q: influent flowrate (m^3/d)

V_d: designed up-flow velocity (m/h)

The total compartment area (Ac) for each reactor was determined using the equation:

$$A_c = A_u * (1 + R_{U:D}) / R_{U:D} \tag{10}$$

A_c: total compartment area (m^2)

A_u: compartment up-flow area (m^2)

$R_{U:D:}$ up-flow to down-flow area ratio (m^2/m^2)

The value of $R_{U:D}$ as determined from existing calculated experimental values. In the course of this work, the value of $R_{U:D:}$ considered was 3 m^2/m^2

The width of each reactor was determined using the equation:

$$r_W = \sqrt{(Vw * Cw:l) / (N * rd)} \tag{11}$$

r_W: reactor width (m)

V_W: working volume of reactor (m^3)

$C_{W:L}$: compartment width to length ratio (m/m)

N: number of compartments

r_d: reactor depth (m)

In this work, each reactor was designed with 06 compartments. The value of $C_{W:L}$ was determined from existing calculated experimental values, and the value considered was 3 m/m. This was same for the depth of the reactors with the value 3 m considered.

The length of each reactor was determined using the equation:

$$r_L = (N * r_W) / C_{W:L} \tag{12}$$

r_L: reactor length (m)

N: number of compartments

r_W: reactor with (m)

$C_{W:L}$: compartment width to length ratio (m/m)

Design of the anaerobic filters (AF)

In this work 02 three-chambered anaerobic filters were designed. The design parameters that were taken into consideration are: hydraulic detention time, volume of the filter, area of the filter, volume of the packed bed and the hydraulic loading rate.

The hydraulic detention time (HDT) for each filter was determined using the expression:

$$HDT = V / Q \tag{13}$$

HDT: hydraulic detention time (h)

V: volume of the anaerobic filter (m^3)

Q: influent flowrate (m^3/d)

The volume of each filter was determined using the equation:

$$V = Q * HDT / 24 \tag{14}$$

The area of each filter was determined using the equation:

$$A = V / H \tag{15}$$

Where:

A: area of filter (m^2)

V: volume of filter (m^3)

H: depth of the filter (m)

H was determined by the expression: $H = h_1 + h_2 + h_3$ where

h_1: value adopted for the packed bed (m)

h_2: height of the bottom compartment (m)

h_3: free depth to the effluent collection launder (m)

The values of h_1, h_2 and h_3 were adopted from existing calculated experimental values and were respectively 1.5, 0.6, and 0.3m.

The volume of each packed bed was determined by the equation:

Where:

$$V_{pb} = A * h_1 \tag{16}$$

V_{pb}: volume of packed bed (m^3)

A: area of the filter (m^2)

h_1: value adopted for the packed bed (m)

The hydraulic loading rate (HLR) was determined using the equation:

$$HLR = Q / A \tag{17}$$

HLR: hydraulic loading rate (m^3/m^2.d)

Q: influent flow rate (m^3/d)

A: surface area of the packing medium (m^2)

Design of the pumping station

The pumping station shall use solar energy technology. The main role shall be to pump the effluent leaving the AF to the planted filter bed. The main design parameter here is the power of the pump. It was determined by the expression:

$$P_e = \gamma * Q * H / \eta \tag{18}$$

P_e: effective power of the pump (kW)

γ: specific weight of water (9.8kN/m^3)

Q: discharge (m^3/s)

H: total head (m)

η: pump efficiency=0.8

Design of the horizontal planted filter gravel bed (HB)

The design of the filter was done following the method proposed by Wegelin (with three filtration compartments: coarse gravel, fine gravel and sand) [9] and the planted bed method proposed by *"Groupe Macrophytes et traitement des eaux"* [10]. The design parameters taken into consideration were:

The cross-sectional area of the HB which was determined using the equation:

$$L_F = L_1 + L_2 + L_3 \tag{19}$$

A: cross-sectional area (m^2)

Q: influent flowrate or hydraulic load (m^3/h)

V_F: filtration rate (m/h)

The value of V_F which was adopted was the calculated experimental value proposed by Wegelin. This value is 0.75 m/h.

The total length of the filter which was determined by the equation:

$$L_F = L_1 + L_2 + L_3 \tag{20}$$

L_F: total length of filter (m)

L_1, L_2, L_3: lengths of first, second and third compartments (m)

The length of each filter compartment was determined as a function of the grain size of each filter media as proposed by Wegelin. That is, 4 m long for coarse gravel (15 mm in diameter) layer, the second compartment is made up of a 2 m long fine gravel (5 mm in diameter) layer and the third compartment is made up of a 1 m long sand (0.4-1mm in diameter) layer.

The width of the filter which was determined by the equation:

$$W = A / L_F \tag{21}$$

W: width of HB (m)

A: area of HB (m^2)

L_F: length of HB (m)

The height of the HB was also adopted considering calculated experimental values propose by Wegelin. In this work a height of 1.5 m was used.

The designed filtration rate which was determined using the equation:

$$VDF = (Q/3) \ / \ W * H \tag{22}$$

V_{DF}: designed filtration rate (m/h)

Q: influent flowrate or hydraulic load (m^3/h)

W: width of HB (m)

H: height of HB (m)

3: since it's a three compartment HB

The total number of plants used was determined following the method proposed by *"Groupe Macrophytes et traitement des eaux"*. Going from the assumption that we have 4 plants/m^2, thus:

$$NP = A * 4 \tag{23}$$

NP: total numbers of plants

A: cross-sectional area of HB (m^2)

Results and Discussion

In this research work, the various units of the proposed wastewater treatment system were designed for 600 active users. This number was chosen based on the fact that when the hospital is at full capacity, all the beds are occupied and each patient has a caregiver. This makes a number of 480. To this, we also have 45 active staff members who spend 24hrs in the hospital daily making the users number climb to 525. Finally, a number of 75 were added to the active users for any short-term future extension of the hospital's number of wards. However, it is important to underline the fact that due to the insufficient land space of the hospital, its eventual extension will be very difficult.

Mathematical design of the different units of the proposed wastewater treatment system

The decentralized wastewater treatment system proposed for the Bamenda Regional Hospital in the course of this work is constituted of: A sewer network made up of 12 main PVC pipes (S1, S2, S3, S4, S5, S6, S7, S8, PS, PS1, PS2 and PS3) which shall transport the wastewaters from the various sections of the hospital to the treatment unit; a settler or settling tank; two (02) six-chambered anaerobic baffled reactor; two (02) three-chambered anaerobic filter and a 3 layered horizontal planted gravel bed.

Dimensions of the sewers

The population distribution per sewer and daily water consumption per user per day; the flow rates (Q in m^3/s) in the different sewer;

the distribution of wastewater flow rates in the different sewers; the dimension of the diameters of the different sewers and the velocity of wastewater in each sewer (V in m/s) is shown with the help of tables (Tables 1-4). The main reasons for the choice of the PVC pipes are its relative affordability, its lightness and impregnability to liquids. The diameters of the pipes range between 50 mm and 80 mm. It is worth noting that the diameter considered for each sewer is the nominal or commercial diameter for each calculated diameter.

To some authors, the daily water consumption in the hospital is 300-600 L/day/bed [11]. In the Roozbeh and Razi hospitals in Tehran, Iran it is 531 L/day/ bed and 1473 L/day/bed respectively [12]. Taking into account the country realities as far as water supply is concerned, the daily water consumption in this work was assumed at 150 L/day/bed and the minimal value of 0.8 was considered for the water which does not end up in the sewer. As shown on the values of the slopes fall in the range 10/00-30/00 (Table 4). The slopes of lying of pipe lines vary in a range of 1% to 3% in order to contain the water speed [13]. The result shows that the velocities in the pipes range between 0.02-0.70 m/s (Table 5). These values can be considered acceptable. This is because generally, the velocity in pipes should be in an allowable range of < 3.

Designed settler

The designed settler is a rectangular settling tank which consists of a T-shaped inlet and outlet pipes (Figure 4). These pipes play an important role as they shall prevent eddy currents and short-circuiting, as well as to retain scum inside the basin. The settler also contains an

Sewer	Connected Unit	Population	Daily consumption (L/day)
S1	Mortuary	10	150
S2	Infectious disease unit, Ophthalmology,restaurant, infant diabetic, dental department, internist, diabetic unit, physiotherapy, Pediatric consultation, dental department,B-Ward, D-Ward	160	150
S3	TB Lab, laboratory, imaginary, day hospital	30	150
S4	New private, C-ward, E-ward	160	150
S5	Anti-natal clinic, F-ward	50	150
S6	Theatre, Reanimation, obstetry, gynecology and family planning, post-natal	55	150
S7	Haemolysis center, intensive health care, labour room, nursery	36	150
S8	Ebola unit, general consultation, A-ward, Blood bank, director's secretary, casualty, doctors on call, driver room, almoner 2, pharmacy	99	150
PS	From all units	600	150
PS1	From all units	600	150
PS2	From all units	600	150
PS3	From all units	600	150

Table 1: Population distribution per sewer and daily water consumption per user per day.

Sewer	Population	Daily consumption (L/day)	Daily peak coefficient (Pd)	Hourly peak coefficient (Ph)	Q (L/day)	Q (m^3/s)
S1	10	150	1.5	1.5	3375	0.00004
S2	160	150	1.5	1.5	54000	0.00063
S3	30	150	1.5	1.5	10125	0.00012
S4	160	150	1.5	1.5	54000	0.00063
S5	50	150	1.5	1.5	16875	0.00019
S6	55	150	1.5	1.5	18562.5	0.00021
S7	36	150	1.5	1.5	12150	0.00014
S8	99	150	1.5	1.5	33412.5	0.00039
PS	600	150	1.5	1.5	202500	0.00230
PS1	600	150	1.5	1.5	202500	0.00230
PS2	600	150	1.5	1.5	202500	0.00230
PS3	600	150	1.5	1.5	202500	0.00230

Table 2: Flowrates (Q in m^3/s) in the different sewer.

Sewer	Q (m^3/s)	ϕ	$Q_{wastewater}$ (m^3/s)
S1	0.00004	0.8	0.00003
S2	0.00063	0.8	0.00050
S3	0.00012	0.8	0.00010
S4	0.00063	0.8	0.00050
S5	0.00019	0.8	0.00015
S6	0.00021	0.8	0.00017
S7	0.00014	0.8	0.00011
S8	0.00039	0.8	0.00031
PS	0.00230	0.8	0.00184
PS1	0.00230	0.8	0.00184
PS2	0.00230	0.8	0.00184
PS3	0.00230	0.8	0.00184

Table 3: Distribution of wastewater flow rates in the different sewers.

Sewer	Q(m^3/s)	L (m)	J (m/m)	K_s ($m^{1/3}$/s)	D (m)	D (mm)	DN (mm)	V (m/s)
S1	0.00003	73	0,041	95	0.01	10	50	0.02
S2	0.00050	280	0,021	95	0.03	30	50	0.30
S3	0.00010	88	0,011	95	0.02	20	50	0.10
S4	0.00050	88	0,023	95	0.03	30	50	0.30
S5	0.00015	82	0,012	95	0.02	20	50	0.10
S6	0.00017	54	0,056	95	0.02	20	50	0.10
S7	0.00011	188	0,016	95	0.02	20	50	0.10
S8	0.00031	120	0,008	95	0.03	30	50	0.20
PS	0.00184	31	0.005	95	0.07	70	80	0.40
PS1	0.00184	32	0,031	95	0.05	50	60	0.70
PS2	0.00184	49	0.005	95	0.07	70	80	0.40
PS3	0.00184	80	0,013	95	0.06	60	80	0.40

Table 4: Dimension of and Velocity in the different sewers.

Settler	Volume (m^3)	Area (m^2)	Depth (m)	Width (m)	Length (m)
Tank	13.25	3.68	3.60	1.84	2.00

Table 5: Dimensions of the designed settling tank showing its characteristics.

access cover which permits access into the tank for any sample collection and control works. The main purpose of this settler is to remove by sedimentation and flotation suspended solids present in the influent.

The principal design parameter was the hydraulic detention time. According for high performance rates at peak flow, settling tanks should be desired for hydraulic detention times of 1.5-2.5 h [7]. This value is also generally considered at 2h for primary settling only or followed by attached growth treatment for flocculant sedimentation at peak flow [14]. In the design of the settler, a hydraulic retention time of 2h was considered due to the fact that treatment was assumed at peak flow with the flocculant sedimentation type of sedimentation. At peak flow with the flocculant sedimentation type of sedimentation, the surface loading rate is generally ≤ 1.8 m/h. A maximal value of 1.8 m/h was considered during the design. Settlers can achieve a significant initial reduction in suspended solids (50-70% removal) and organic material (20-40% BOD removal) and ensure that these constituents do not impair subsequent treatment processes. Other research works states that, the settlers has a removal efficiency of 25-40% BOD5, 20-30% COD, 40-70% SS, 10-20% N, 5-10% P and 50-60% bacteria.

Designed anaerobic baffled reactors

The purpose for using the anaerobic baffled reactor is to provide enhanced removal and digestion of organic matter as well as micro-organisms present in the influent. The diagrammatic representation of the designed anaerobic baffled reactors and its characteristic dimensions is shown below (Figure 5).

The design objective was to maximize the amount of contact time between suspended or dissolved contaminants and the biomass and minimize the amount of sludge washout in the ABR effluent. This can be achieved by maximizing the hydraulic retention time (the treatment time), the number of passes through the sludge bed (i.e. number of compartments) and minimizing the up-flow velocity to reduce solids carry-over, determined by solids retention, within the constraints of space and capital cost. In order to obtain maximum treatment rates, two 6-compartment anaerobic baffled reactors to be placed in series were designed. These designed two 6-compartments ABR offers a hydraulic retention time of 96h (48h for each ABR) far higher than the ranges of 48-92h for high performance rates at peak flow and the 20-60h which permitted high treatment performances for domestic wastewaters. The value of the peak up-flow velocity (0.54 m/h as recommended by Foxon and Buckley) and peak flow factor (1.8) gave an up-flow velocity of

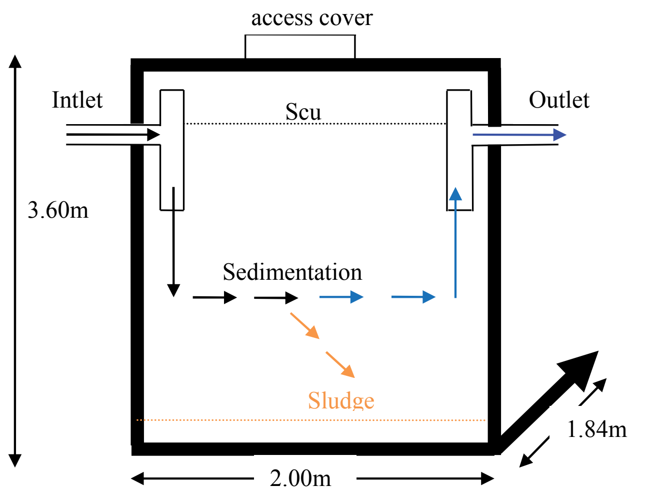

Figure 4: Diagrammatic representation of the designed settler.

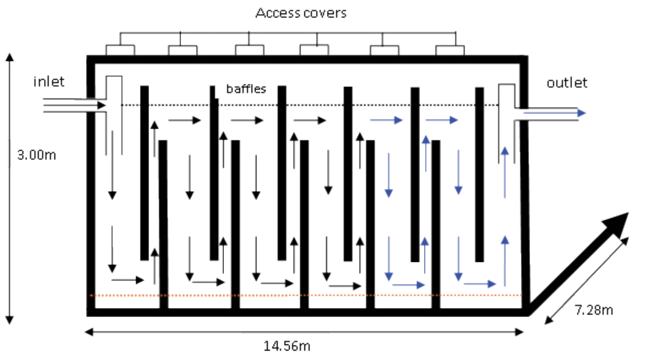

Figure 5: Diagrammatic representation of the designed anaerobic baffled reactors.

0.30 m/h. This value is in correlation with the one recommended by Tilley et al., which according to them should be <0.6 m/h [7]. It is worth noting that a peak flow factor of 1.8 revealed to be adequate for design purposes as shown by studies on simplified sewerage (small bore sewer systems) in poor communities in Brazil.

The designed ABRs also offer an increased number of compartments. Increasing number of compartments permits increase intimate contact between sludge and wastewater, thus ensuring efficient use of the treatment volume and overall removal of COD. The objective of using two 6 compartment reactors (raising the number of compartments to 12) is to increase the intimate contact between the sludge and the wastewater so as to improve treatment. This goes in line with the works of Boopathy showed that for 4 ABRs with 2, 3, 4 and 5 compartments respectively, and with all other dimensions identical, more compartments resulted in better solids retention and overall greater extent of treatment for a swine manure feed [15]. Anaerobic baffled reactors may reduce BOD by up to 90%, which is far superior to its removal in a conventional Septic Tank. According to the project data sheet of the "Decentralized Wastewater treatment facility for a Public Market Project" in Philippines in 2007, anaerobic baffled reactor which reduces the BOD/COD content from 20% to 85%. This technology is used in the DEWATS of the Aravind Eye hospital in India. Reports from the hospital reveal that the ABR reduces BOD by 75%.

Designed anaerobic filters

Two square 3-chambered anaerobic up-flow filters to be placed in series were designed with granite stones used as the filter medium (Figure 6). The objective of this technology is to improve treatment, as the influent leaving the ABRs shall flow through the filter (Table 6). Particles are trapped and organic matter is degraded by the active biomass that is attached to the surface of the filter material or packing medium. The major designed characteristics taken into consideration were the volume of the filter, its area, length, depth and width. The dimensions and the characteristics of each chamber of the designed filter are shown in the table (Table 7). The volume of the filter was designed as a function of the influent flow rate and the hydraulic retention time. According to Tilley et al., the range of the hydraulic retention time for efficient treatment is between 12-36 h [7]. Other authors like Carlos recommended a hydraulic retention time ranging between 4-10 h [15]. For purpose of treatment improvement, the maximal value of 10 h for each filter (making a total of 20h) for the hydraulic retention time was used to design the their volumes.

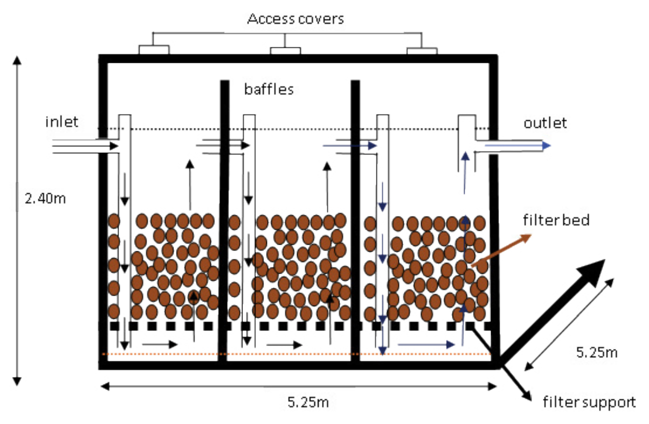

Figure 6: Diagrammatic representation of the designed anaerobic filter.

The area of the filters was determined as a function of their volumes and depths. The depth of the filters was the sum total of the adopted value of the packing medium height (h1), the height of the bottom compartment (h2) and the free depth to the effluent collection launder (h3) for each filter. Based on the Brazilian National Research Programme on Basic Sanitation, PROSAB [16], using anaerobic filter filled with a stone bed for the polishing of effluents from septic tanks and UASB reactors, the recommended value for h1 should be in the range 0.8-3.0 m. A more usual value should amount approximately to 1.5 m. Adopted values for h2 and h3 are 0.6 and 0.3 m respectively. The value of h3 is the same as that recommended by Tilley et al., Therefore, the values 1.5, 0.6, and 0.3m were respectively used as values of h1, h2 and h3 for the determination of the depth of the filters [7].

Other important designed components of the filters were the volume of the packed bed, the hydraulic loading rate and the filter medium. The volume of the packed bed was a function of the area of the filters and the packing medium height (h1). The hydraulic loading rate on its part defines the volume of wastewater which when applied daily per unit area of packing media will produce effluents of good quality. The value of 5.76 $m^3/m^2/d$ was designed as the hydraulic loading. Results of studies developed by the Brazilian National Research Programme on Basic Sanitation, PROSAB, using anaerobic filter filled with a stone bed for the polishing of effluents from septic tanks and UASB reactors, showed that the filters are capable of producing effluents of good quality when operating under surface hydraulic loading rates ranging from 6-15 $m^3/m^2/d$. Granite stones with sizes ranging from 12-55 mm were considered as the packing medium. This choice was based on the fact that granite stones are locally available and affordable. With the anaerobic filter technology, suspended solids and BOD removal can be as high as 90%, but is typically between 50% and 80%. Nitrogen removal is limited and normally does not exceed 15% in terms of total nitrogen. This technology has been used in the Decentralized Wastewater treatment facility for a Public Market Project" in Philippines in 2007and most hospitals in South East Asia, notably in the DEWATS of the Aravind Eye hospital in India with reports revealing over a 90% reduction of the original pollution load. Effluents from anaerobic filters are usually well clarified and have a relatively low concentration of organic matter, although it is rich in organic salts.

Designed pump

The reason for designing the pump in this work was due to the fact that sewer PS1 has to face an ascending slope with an altitude of 1 m through a 32 m distance to PS2. The pump has to effectively pump water from the anaerobic filter through PS1 to PS2. The effective power of the pump was determined as a function of the influent discharge, the specific weight of water, the total head and the pump efficiency. The total head is the sum total of altitude at which the influent is to be pumped and the head loss. The altitude of 1 m was considered and the head loss 0.47 m. The specific weight of wastewater is more

Reactor	Working volume (m^3)	Compartment up-flow area (m^2)	Total compartment area (m^2)	Reactor depth (m)	Reactor width (m)	Reactor length (m)
Anaerobic Baffled Reactor	317.95	22.08	29.44	3.00	7.28	14.56

Table 6: Dimensions of the designed anaerobic baffled reactors showing their characteristics.

Filter	Volume (m^3)	Area (m^2)	Depth(m)	Volume of packed bed (m^3)	Width of filter (m)	Length of filter (m)
Filter chambers	22.08	9.2	2.40	13.8	5.25	1.75

Table 7: Dimensions of each of the 3 chambers of the designed anaerobic ilters showing their characteristics.

or less same as that of water. Thus the value of the specific weight of water (9.8kN/m^3) was used. The efficiency for most pumps is usually considered at <1, generally 0.85. A value of 0.85 was considered. This gave a pump effective power of 0.03KW. The pump shall use the solar energy technology. This is due to the fact that, just like most towns of the country, Bamenda faces a lot of electrical power shortages.

Designed horizontal planted gravel bed

The horizontal planted gravel bed designed in this work combined the horizontal flow roughing filter technology as described by Wegelin and the planted bed method described by "Groupe Macrophytes et traitement des eaux" (Figure 7). The main characteristics of the process are its horizontal flow direction and the graduation of the filter material. The filter bed consists of 3 filtering layers (coarse gravel, fine gravel and sand) of different sizes. below respectively show dimensions of the designed horizontal planted filter bed and dimensions of the different layers of the designed horizontal planted gravel bed showing their characteristics (Tables 8 and 9).

Besides solid matter separation, roughing filters also partly improve the bacteriological water quality and to a minor extent, change some other water quality parameters such as colour or amount of dissolved organic matter. The main designed characteristics considered were the cross-sectional area of the filtration bed, its length, width and height. Another characteristic of interest is the size of the different filtration media and their length. The area of the filtration bed was a function of the influent flow rate and the filtration rate. In a design guideline proposed by Wegelin, the filtration rate for high (>300 mg/l), medium (300-100 mg/l) and low (100 mg/l) suspended solid concentrations in pre-settled wastewater is 0.5, 0.75-1, and 1-1.5 m/h respectively. During this research, it was assumed that the influent at this level is of medium concentration since it has passed through five other treatment units. Thus the value for the filtration rate that was used alongside the influent flow rate in order to determine the cross-sectional area is 0.75 m/h. [17], good removal in roughing filters is best achieved with low filtration rate because low filtration rates are critical to retain particles that are gravitationally deposited to the surface of the media. Other researchers such as Hendricks (1991) suggested that normal filtration rate of horizontal roughing filters is between 0.3 and 1.5 m/h [18].

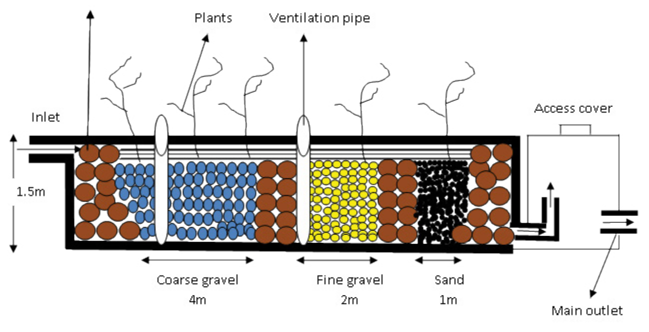

Figure 7: Diagrammatic representation of the designed horizontal planted gravel bed.

As for the length of the filtration bed, the treatment efficiency increases with longer beds, though this depends on the sizes of the filtration material. These different compartment lengths were chosen from the design guidelines propose by Wegelin. Since we assumed that the influent at this level is of medium concentration, the guideline outlines for such concentrations a length of 2-4 m for coarse gravel of diameter 15 mm and a length of 1-2 m for fine gravel of diameter 5 mm. Maximal values of length were considered in the design so as to provide characteristics that can permit improved treatment. The width of the filtration bed was determined using the cross-sectional area and the length of the bed. The height used during the design of the filter was 1.5 m. According to Wegelin, the height of the side walls should lie between 1.0 and 1.5 m. Such side wall heights can enable an easier removal and refilling of gravel from and into the filter as well an effective reduction in its construction cost.

The direction of flow of the influent can also impact the treatment efficiency. The horizontal flow roughing filter presents certain advantages compared to the vertical flow filters. Horizontal roughing filters have a large silt storage capacity. They also react less sensitively to filtration rate changes, as clusters of suspended solids will drift towards the filter bottom or be retained by the subsequent filter layers thus they are less susceptible than vertical-flow filters to solid breakthroughs caused by flow rate changes [19]. This technology has been used in most pilot plants in the world. A pilot plant was constructed in Malaysia by Nordin Adlan and he examined and evaluated the removals of turbidity, suspended solids and BOD and coliform organisms from wastewater using different sizes of limestone roughing filter. Results indicated that removal efficiencies depended on the size of the filter medium and applied flow rates. Turbidity, suspended solids, BOD and coliform organisms' removals were between 75 and 92%, 79 and 88%, 51 and 67% and 67 and 96%, respectively, in a combination of the 3 filter media with particle sizes between 1.91 and 16.28 mm. The introduction of planted reeds to the horizontal flow rough filter technology simple goes a long way to improve treatment efficiency. According to the *"Groupe Macrophytes et traitement des eaux"* each m^2 of the filtration bed should contain four (4) plants. During the designing, since the cross-sectional area is 8.83 m2, the total number of plants is 36. The plants and their root systems maintain the porosity of the filter. They also re-oxygenate the influent depriving it from bad odor.

The horizontal planted gravel bed technology has been used for post-treatment in many DEWATS in Asia. It the cases of the DEWATS at the Kachpura village in Agra Delhi-India operational since 2010, which comprises of a :screen chamber; three chambered septic tank; nine chambered baffled anaerobic reactor filled with gravels and a planted filter bed containing three different types of filter media (white river pebbles, red stone and gravels) [20]. It is reported that this system reduces BOD, COD and TDS by 61%, 64% and 91%.

Another example is the DEWATS at the Bankers Colony, Bhuj-India

HB	Cross-sectional Area (m^2)	Total length(m)	Width(m)	Height (m)	Designed filtration rate (m/h)	Total number of plants
Horizontal planted bed	8.83	7.00	1.26	1.50	1.17	36

Table 8: Dimensions of the designed horizontal planted ilter bed showing its characteristics.

Characteristics	Coarse gravel	Fine gravel	Sand
Length (m)	4	2	1
Diameter (mm)	15	5	0.4-1

Table 9: Dimensions of the different layers of the designed horizontal planted gravel bed showing their characteristics.

operational since 2006, which comprises of a: two chambered settler; nine chambered anaerobic baffled reactor with an anaerobic filter in the last two chambers; a planted filter and polishing pond [21]. Reports reveal that this system reduces BOD, COD and TDS by 91%, 81% and 98% respectively. In the same perspective, we can talk of DEWATS Friends of Camphill, Bangalore-India operational since 2003[22]. It comprises of a: common collecting chamber; a dome shaped biogas settler; 16 chambered baffled reactors; horizontal planted gravel filter and a polishing pond. Reports say the system reduces BOD, COD and TDS by 92%, 91% and 94% respectively.

Cost efficiency of the proposed system

The cost for the construction of such a treatment system is estimated at 272.648 USD. This cost is relatively low compared to those of other technologies used in the treatment of hospital wastewaters. This is the case of the wastewater treatment plant of the Herlev Hospital in Denmark (constructed under the private-public innovation project) whose cost was estimated at 6.923.982 USD. Another example is the wastewater water treatment system of the Marien Hospital Gelsenkirchen (constructed under the pills pilot-project). Its complex technology gave an estimated cost price of 9.717.889 USD.

Conclusion

The Bamenda regional hospital just like most hospitals in Cameroon lacks a wastewater treatment unit or system. The inappropriate management of this hospital's wastewaters presents health risks and environmental pollutions. Thus, the necessity for the design of an appropriate wastewater treatment system. The proposed wastewater treatment system designed in this paper for the appropriate treatment of the hospital wastewaters is a decentralized system made up of: A combination of four treatment technologies. It consists of a: Settling tank for the removal by sedimentation and flotation of suspended solids present in the influent; two 6-chambered anaerobic baffled reactors placed in series for the enhanced removal and digestion of organic matter as well as micro-organisms present in the influent; two 3-chambered anaerobic filters for improved treatment; a horizontal planted gravel bed to improve the bacteriological water quality and to a minor extent, change some other water quality parameters such as color or amount of dissolved organic matter.

The choice of the system proposed in this work was governed by the fact that: the cost of construction, operation and maintenance of the different treatment units is relatively low compared to other technologies; the construction materials are locally available; the system does not require large area since the units are constructed underground; the system energy requirement is very low or almost zero; reports from researchers reveal that the different units combined in the chosen system have individually shown good treatment efficiencies.

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