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Research Article

FAECAL SLUDGE ECO-TREATMENT DESIGN SYSTEM PROPOSAL IN A TROPICAL CLIMATE: CASE STUDY OF BAFOUSSAM WESTERN- CAMEROON

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ABSTRACT

In order to propose an eco-technological approach for the treatment of faecal sludge in the city of Bafoussam, which takes into consideration the physico-chemical, bacteriological and climatic parameters of the city of Bafoussam, the approach used can be adapted to another context through parametric adjustments. To carry out this study, we opted to design an autonomous treatment system on a planted drying bed. For this, we first analyzed the physico-chemical characteristics, namely: Total solid (TS), Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), Hydrogen Potential (pH), Orthophosphates, Nitrate and bacteriological (Escherichia coli (E. coli), Streptococcus) of Faecal Sludge (FS) in order to determine the quantity of sludge and the quantity of polluting material. In view of faecal sludge characteristics, we opted for the sizing of the different compartments of the station (bar screen, storage basin, drying beds and lagoons). Considering population growth, the amount of mechanically drainable sludge by 2032 is estimated at 28539.30 m3. year-1. For the treatment of this quantity of faecal sludge, it will be necessary, according to the calculations, to treat 110.73 t. year-1 of dry matter for a surface load of 200 kg.m-3. year-1 and a pollutant load of 38.8 kg/ MS /m 3. Regarding the area required to contain all the compartments of the station, it will be necessary to provide 5536.62 m^2.

Keywords: Faecal sludge, Pollutants abatement, Eco-technology, Sludge, Water and Sanitation.

INTRODUCTION

The population explosion observed in recent decades has rendered existing sanitation methods obsolete, thus making populations vulnerable to the effects of poor waste management, particularly in developing countries where the urbanization plan is precarious and sanitation levels are very low and are around 16% for sub-Saharan countries (WHO, 2018). According to the WHO, the low level of sanitation exposes the population to a significant health risk. Indeed, it is one of the causes of diarrheal diseases which affect several million children in the world, and are responsible for both the development of malnutrition and economic losses.

In addition, good waste management (solid or liquid) effectively contributes to improving living conditions and protecting the environment. Aquatic environments, which are the receptacles and witnesses of all types of pollutants (Point, 1999), are seeing their quality deteriorate and their biological diversity drift due to certain anthropogenic activities (Fouillet, 2019). This degradation of water quality over the years due to poor sanitation makes access to drinking water very difficult. Therefore, it was agreed by States in New York in 2000 during the millennium summit, to reduce to halve the rate of the population without access to drinking water and to an adequate system of sanitation by 2015. This has failed in several developing countries, partly due to lack of knowledge and mastery of waste management technology (wastewater and faecal sludge).

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Encountered with these challenges and requirements, sanitation will rise to another level with the development of less expensive eco-technologies adapting to the context of developing countries or those with low incomes. These technologies mimic naturally occurring phenomena to treat and valorization of faecal sludge (FS). These technologies, which are largely dependent on chemical, physical and biological characteristics, have so far made it difficult to implement a universal approach to the design of FS treatment devices due to the chemical, physical and biological variability of sludge. These parameters, which vary widely by location and even more by climatic zone, make system performance in different countries unpredictable. In other words, designing a faecal sludge treatment plant means considering the chemical, physical and biological parameters specific to each type of sludge in the area to accommodate the treatment device. In Cameroon, the poor management of the FS is widely felt in the metropolises where the population density is high. Most of the sludge is dumped in the nature and in places known by all: in Douala at a place called the Monkey Bridge, in Yaoundé at a place called Mbankomo in Bafoussam along the banks of the Noun River. To remedy to this increasingly growing scourge, eco-technologies for the treatment of FS have been designed in these different cities, considering validated models of stations present in other countries with a very different climate and sludge characteristics from that of Cameroon. This may justify the malfunctions observed in all these treatment stations.

We will dwell on FS in the city of Bafoussam, by taking into consideration the physico-chemical and bacteriological parameters of the sludge and subsequently to propose a conceptual method for sizing the FS treatment mechanism on a planted drying bed responding to the physico-chemical and bacteriological characteristics of sludge in Bafoussam. This will make it possible to limit operating failures due to the importation of technologies from climatic contexts and different sludge characteristics, as it was the case with several stations in other regions of Cameroon.

MATERIALS AND METHOD

Localization of the study area

The municipalities of Bafoussam II and Bafoussam I are located at the North longitude of coordinate 5° 30' and the East latitude of coordinate 10° 33', the altitude a maximum altitude point 1560 m. These municipalities are in the Division of Mifi, West Region Cameroon. The Municipality of Bafoussam II is the locality likely to host the future station, covering an area of 219.3 km 2 and has 70 villages, 26 of which are in the urban area and 44 in the rural area. The climate of West Cameroon is mild and cool, with a dry season (mid-November to mid-March) and a rainy season (mid-March to mid-November). Precipitation is 1800 mm of rain per year (Mpakam, 2006). The relief is made up of a succession of hills with steep slopes. Geologically, the city of Bafoussam is built on plateau basalts from ancient volcanism) (Dongmo, 1985). On the pedological level, the soils of the city of Bafoussam are part of the large sets of highlands of Western Cameroon, they are of the ferralitic type, little evolved and hydromorphic (Tsalefack, 1988).

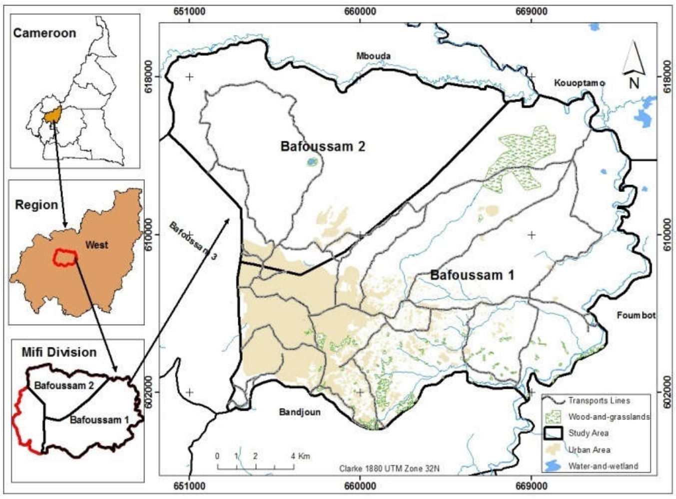

Figure 1: Area of study

Conceptual approach of a FS treatment station

Physicochemical characteristics of faecal sludge

Knowledge of the characteristics of sludge is an essential element in the design of a fecal sludge treatment process. Given the high variability of FS characteristics within the same city, we cannot use data from the literature alone to estimate the design parameters (Mahamane, 2011). A characterization campaign is therefore necessary. The methodology used for the characterization is based on the sampling of FS and laboratory analyses. For the characterization of faecal sludge, we carried out analyzes on sludge samples taken during deporting at various places in the city. The samples were taken when the emptying trucks were unloaded. The sludge was taken in bottles at the start of unloading (0.5 l), when the tank was half empty (0.5 l) and just before the end of unloading (0.5 l) as recommended by (Klingel *et al.,* 2002) and immediatlily transported to the lab to analyse the physico-chemical and bacteriological parameters.

Table 1: physico-chemical and bacteriological parameters

Physico-chemicalparameter	Methods and Apparatus
pH	The pH measurement was determined using a Hach brand pH meter (HQ11d). After prior calibration of the pH meter using buffers with values of 7.00 and 4.01
COD	The COD was determined by chemical oxidation in a strong sulfuric acid medium with an excess of potassium dichromate ($K_2Cr_2O_7$) for two hours. Then the reading was made with the Spectrophotometer DR 2000 HACH
TSS	TSS are determined using a Hach DR/2000 spectrophotometer. After introducing 10 ml of sample into a spectrophotometric cell
TS	For total solids, 100 ml of well-homogenized raw faecal FC will be evaporated in crucibles and dried to constant weight at 105°C.
Phosphate ions	The introduction of 10 ml of sample in a spectrophotometric cell, a sachet of RGT phosphate is added. The color developed in the presence of PO_3^- is then read on the digital display screen of the device by reference to a witness (distilled water).
Nitrate	Introduction of 10 ml of sample into a spectrophotometric cell, homogenized and left to stand for 5 minutes (reaction time). The nitrate content is read on the device's digital display screen by reference to a control (distilled water)
Biologicalparameters	
E. coli	Chromo cult Agar culture medium was used to grow the bacteria and a digital colony count was used to count all bacterial colonies.
Streptococcus	The spreading method on culture media recommended by the French Association for Standardization (AFNOR)

Sizing of the different compartments of the treatment system

Evaluation of the quantity of FS produced

The quantities of sludge to be evacuated and/or treated represent an essential parameter for planning improved management of FS (Kouanda, 2006). Four sludge quantification methods have been developed by the same author based on the criteria which are:

- Specific production (method based on sludge production in l/day/inhabitant per type of latrine);
- The demand for mechanical emptying (consists of listing all the trips made by the emptying operators and multiplying the figures found by the volume of the respective trucks);
- The characteristics of the works (this approach consists of calculating the sum of the volumes that can be drained in the city and according to the type of latrine);
- The turnover of the emptier (by knowing the price of an emptying and the volume of the truck, we can deduce the quantity of emptied sludge).

Within the framework of this study, the second method based on the demand for mechanical emptying will be used for the calculation of the quantities of sludge produced because it makes it possible to evaluate the production of sludge mechanically emptied which is the quantity of sludge arriving at the station of treatment. Moreover, it is more suitable for planners (consultants, municipal technical services) (Kengne *et al.,* 2006).

This method uses parameters such as the number of rotations carried out per truck and per day, the volume emptied per rotation, the average frequency of emptying of the installations and the proportion of the population using the truck service (Défo, 2006).

$$Qmec = N * \frac{Pmec}{fméc} * Vi * ni \qquad (1)$$

Pmec: (%) is the proportion of structures drained mechanically;
fméc: (year) is the frequency of emptying the structures mechanically;
Vi: (m3/rotation) is the useful volume of the truck;
ηi: (rotation/structure) the number of rotations required to empty a structure;
N: is the total number of structures existing in the locality;
Qmec (m^3. $year^{-1}$) is the total quantity of sludge produced.

Sizing of the different compartments of the die

The eco-technological system that we have set up is an autonomous system that mimics natural phenomena. This said exploits the geomorphological configuration of the environment. In the various sub-compartments presented below, the arrangement is made along a drop where the FS reception devices are upstream, followed by the treatment device and finally the refining device. This is in order to allow free circulation of sludge along the slope (Figure 3).

Screen

It retains sludge, large particles likely to interfere with subsequent treatment or damage equipment. Indeed, this waste cannot be eliminated by a biological treatment, it must therefore be eliminated mechanically. The determination of the screen the dimensions comes to determine the section of the screen, the wetted oblique length of the screen, the width of the screen.

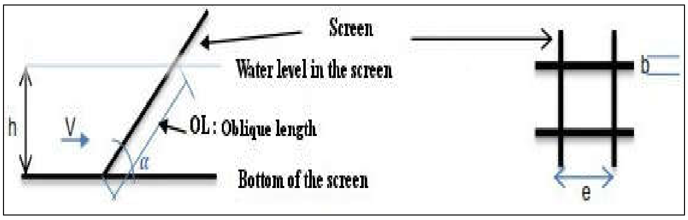

Figure 2 : Screen Illustration

- **Grid Section**

$$s = \frac{Qr}{VOC} \qquad (2)$$

S: minimum grid section,
Qr: discharge flow,
V: delivery speed
C: clogging coefficient

$$O = \frac{Spacing\ between\ bars}{Free\ space + Bar\ diameter}$$

- **Wetted grid length**

$$OL = \frac{t}{sin\alpha}, \qquad (3)$$

t: pulling mud

- **Grid width**

$$l = \frac{s}{OL} = \frac{Qp}{0{,}180 \times t} \times 0{,}44 \qquad (4)$$

The width to adopt: commercial width $> \frac{S}{Lo}$(theoretical width)

Screen characteristics in accordance with typical design values for mechanical screens:

Table 2: Characteristic of the screen

Spacing between bars	e (mm)	15
Bar diameter	b (mm)	10
Clogging coefficient	vs (-)	0.5
Angle of inclination	α (°)	30

Storage cover

It is a semi-buried tarp which is designed to accommodate four times the volume of mud dumped by a vacuum truck which is 10m ^{3}. So the circular tarpaulin will have a volume of 40m ^{3} (being able to contain an average of three unloading per day) it remains to determine the diameter and the depth.

drying bed

The drying beds are semi-buried rectangular in shape and can accommodate up to 1.5 meters of dry matter (Nielsen, 2005). Sizing comes down to determining:

Number of drying beds to be set up

The number of beds must be greater than the ratio of number of days of rest to number of food:

$$number of drybed = \frac{number of resting days}{number of feeding days} \qquad (5)$$

Amount of dry matter per year

$$QMS = Qs \times Qmec$$

QMS: ($kg.m^{-3}$) quantity of dry matter in cubic meter of FS
Qmec: ($kg.year^{-1}$) is the annual quantity of FS

Area load retained

According to studies by Kengne (2010); Dodane & Bassan (2014) proposes an annual surface load of between 150 and 200 kg $MS.m^{-2}$ $.an^{-1}$. For this study we will use a surface load of 200 kg MS. m^{-2}.$year^{-1}$

Total bed area

$$St = QMS/Qs \qquad (6)$$

QMS: (kg/year) is the amount of dry matter per year
Qs: ($kg.m^{-2}$ $.an^{-1}$) is the annual surface load in dry matter

Surface of a bed

$$Sl = \frac{St}{number\ of\ dry\ bed} \qquad (7)$$

St: (m^2) is the surface of the beds

Maturation basin

The percolate resulting from the dehydration and mineralization of faecal sludge will be collected in the maturation basin. The main role of this basin is the destruction of pathogenic microorganisms either by exposure to solar radiation or by sedimentation. According to Dodane (2011) and Kengne (2010) the length/width ratio must be less than or equal to three ($\frac{L}{l} \leq 3$). Percolate retention time should be between 5 and 7 days and depth between 0.5 and 1.5 meters (Compendium of Remediation Systems and Technologies (2016).

$$Ts = \frac{2V}{2Q - 0.001AE} \quad (8)$$

St: residence time

V : percolate volume

Q : percolate flow

A: basin surface

E: evaporation

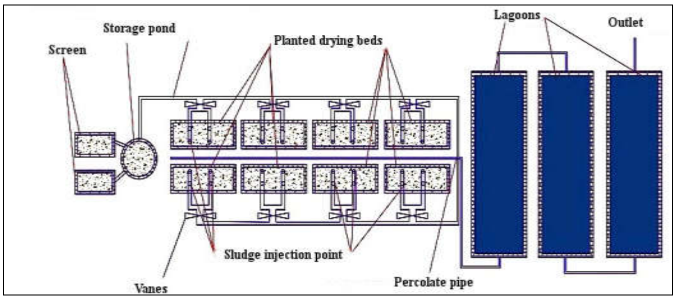

Figure 3: Conceptual device of the FS treatment station

RESULTS

Analysis of physicochemical and bacteriological parameters of FS

Characteristics physicochemical parameters

All the samples taken were analyzed in the laboratory. Table 3 presents the results on the physico-chemical characteristics of faecal sludge in the study area.

Table 3: Physico-chemical characteristics of F S.

Settings Physico-chemical	Raw faecal sludge discharge in Bafoussam	WHO allowable value for wastewater discharge
COD (mg/l)	35300	30
TSS (mg/l)	1480	0.75
TS (mg/l)	38800	1000
pH	7.7	6.6-8.5
PO_4^{3-} (mg/l)	1008.2	3.5
$NH4_+$ (mg/l)	1403.4	50
Conductivity(n/cm)	2124	1250

Bacteriological characteristics

These bacteriological analysis results are summarized in Table 4 showing the minimum and maximum average between the different sludge samples submitted for analysis.

Table 4: Bacteriological characteristics of FS

Indicator	Mean	Minimum	Maximum
E-coli (CFU/100ml)	$1.6*10^7$	$1.1*10^7$	$1.95*10^7$
Streptococci (CFU/100ml)	$4.2*10^7$	$1.8*10^7$	$5.8*10^7$

COD, DM, ortho-phosphate and nitrate values are high. They are higher than those recommended by the discharge standards (7800 mg/l for COD). Several studies (Kottatep *et al.,* 1999; Montangero *et al.,* 2002; Kengne, 2006 ; Troesch, 2009 ; Mahamane, 2011) show that the characteristics of FS vary greatly within the same city. The values of our parameters also compared to those of (Kengne, 2006) ; (Dème *et al.,* 2009) are totally variant for each parameter.

This proves that the quality of the FS in these different areas is influenced by: the frequency of emptying, the climate, the type of sanitation structure, the method of emptying. The percolate from the FS of Bafoussam is loaded with mineral substance, in this case Orthophosphate 1000 mg/l and nitrate 1400 mg/l. likely to contribute to the eutrophication of the environment receiving effluents. The pH values obtained revolve around neutrality.

Assessing the quantity of FS to treat

Presented in Table 5 reviews all the parameters necessary to quantify faecal sludge over a period of ten years which is the duration from which one can begin to observe loads greater than the reception capacity of the station.

Table 5: Quantity of sludge mechanically drained by 2032

Designation	Values
N	33940
P mech (%)	67.27
f mech (year)	4
vi(m^3)	10
Hi	0.5
Q mech ($m^3.an^{-1}$)	28539.30

The bacteriological analyzes showed that the FS sampled were all contaminated with the germs sought. The average concentration of E-coli is 1.6*107 UFC/100ml and that of Streptococci is 4.2*107 UFC/100ml. These data prove that FS from Bafoussam are highly pathogenic. This can be justified by the fact that 41% of the population uses septic tanks against 59% who use latrines (Défo, 2006), excluding FS from latrines are known for high levels of pathogens (Lénard *et al.,* 2009).

Pretreatment device

- ✓ **Bar screen**

We have summarized the sizing results for the bar screen in Table 6. This table allows you to see more precisely the quantity measurements of the various bar screen equipment.

Table 6: Bar Screen Data Summary

Settings	Parameter values
Influent velocity ($m.s^{-1}$)	0.3
Delivery rate ($m^3.s^{-1}$)	0.011
Useful surface of the grid (m^2)	0.20
Oblique grid length (m)	0.70
Grid width (m)	0.29
Bottom slope (%)	0.05
Screen surface (m^2)	3.75

- ✓ **the storage basin**

The storage basin it will be equipped with:

- Two submerged pumps, placed at the two angles separated by the length for the discharge of the FS towards the beds;
- A sufficiently powerful agitator is recommended, the start-up of which is programmed at least fifteen minutes before the start of pumping, to homogenize the product before injecting it into the beds.
- The storage basin will have a volume of at least equal to that of four (04) trucks, that is to say 40m^3. The dimensions of the storage pond are summarized in Table 7.

Table 7: summary of storage basin data

Basin size	Values
Useful volume (m^3)	40
Diameter (m)	2.52
Height (m)	2
Revenge (m)	0.5

FS treatment device

✓ **The drying beds**

The drying beds are rectangular in shape, composed of a raft made up of a geo-membrane. The beds are sized with an allowable pollution load of 200 kg MS/m²/year, with a feeding frequency of four days, corresponding to a rest period of 30 days. They will have slopes of slopes of 1/2, and a bottom slope of 0.05% and covered with a layer of compacted clay. The beds will be separated by 1 meter to allow visits and equipment checks. The percolate drainage network, bed supply and ventilation pipes will be made of PVC. Table 8 groups together all the bed sizing values.

Table 8: Sizing summary

Designation	Values
Pollutant load (kg MS.m^{-3})	38.8
Quantity of dry matter per year (t.an^{-1})	110.73
Surface load retained (kg.m^{-2}.an^{-1})	200
Required area (m²)	5536.62
Bed area (m^2)	692
Number of bed	8
Number of macrophytes	2768

✓ **Maturation basin**

The maturation basins are 03 in number and are sealed and operated in series. They will make it possible to ensure asepsis of the effluents before their discharge into the natural environment (Paing and Voisin, 2005). Table 9 summarizes the dimensions of the maturation tank necessary for the treatment of percolate.

Table 9: Summary of data on the maturation basin

Basin size	Values
Useful volume (m ^{3})	416.25
Flow (m ^{3}.s^{-1})	59.46
Theoretical retention time (days)	7
Length (m)	37
Width (m)	15
Height (m)	0.75
Revenge (m)	0.25

The population in the district municipality of Bafoussam II was 149,662 inhabitants. With a growth rate of 2.6% according to BUCREP, (2014) and an average household size of 6 people per household (Défo, 2006) we extrapolated the population and the number of households in the district of Bafoussam II by 2032, which we then assimilated to the number of sanitation structures (Kouanda, 2006). The total number of independent works was estimated on the basis of the number of households obtained in relation to the rate of equipment in sanitation facilities. The parameter is ηi of 0.5 and the useful volume of the truck is 10m3 (useful volumes of trucks).

CONCLUSION

Within the framework of this study, where we were call to design a faecal sludge treatment drying bed device meeting the physico-chemical and bacteriological characteristics of Bafoussam sludge. As a result, the microbiological and bacteriological parameters of Bafoussam faecal sludge are clearly different from other sludge collected in other cities and countries around the world. During our field studies, it was found that the malfunctioning observed in the treatment stations present in Bafoussam stems in part from the importation of foreign technologies without calibration or adjustment to the tropical climatic context. So as a respond to that we have developed a conceptual approach that takes into consideration the climatic conditions as well the microbiological and bacteriological characteristics of Bafoussam faecal sludge. This approach can be implemented in several other tropical areas by adjusting the input parameters.

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