CHEMICAL ENGINEERING TRANSACTIONS

VOL.

A publication of AIDIC

The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors:

ISBN 978-88-95608-xx-x **ISSN** 2283-9216

Sequential treatment of municipal wastewater and valorization of filtering media

Jacques R. Njimou[a,d]*, Diana B. Tambe[b], Annie S. Nana[c], S. Andrada Maicaneanu[d]*, Armel A. Noujep[e], André Tallab[e], Nkeng G. Elambo[b]

[a]School of Chemical Engineering and Mineral Industries, University of Ngaoundere, P. O Box 454 Ngaoundere, Cameroon
[b]Research Center, National Advanced School of Public Works, P.O. Box 510, Yaoundé, Cameroon
[c]Center for Developpment Research, University of Bonn, P.O. Box Genscherallee 3, 53113 Bonn, Germany
[d]Madia Department of Chemistry, Indiana University of Pennsylvania, Indiana, PA, 15705, USA
[e]Energy, Water and Environment Lab., NASE, University of Yaoundé I, P. O. Box 8390 Cameroon
* Correspondence to Jacques R. Njimou (njimoujacques@gmail.com & j.njimou@iup.edu)
S. Andrada Maicaneanu (sanda.maicaneanu@iup.edu)

Despite the wide availability of water in communities, sufficient water supply remains a major challenge in developing contries. Most human activities, such as agro-industrial activities require enormous amounts of water. Unfortunately at the tail end of such activities, large volumes of wastewater containing various pollutants are released into the environment leading to its degradation.
This work aims to provide sustainable use of agro wastewater use in the city of Yaounde. With a source of low cost agricultural waste available, corn cobs, this work proposes the development of a sequential filtrating system for municipal wastewater treatment. A treatment process has been designed to recover C, N, P and to remove hazardous microorganisms in the wastewater. With pollutant removal efficiencies between 51 and 95%, the proposed system allows the production of a water effluent readily to be used in agriculture, while the waste filtering materials can be converted to compost and further used for biofarming.

1. Introduction

Water constitutes one of the most important factors of human as well as plant and animal lives. Its availability is a crucial factor for global development. From an economic point of view, namely in developing areas and particularly at the household level, the availability of drinking water saves time allocated for leisure, economic activities, and childrens' education (Singh, 2013). Although being the most precious component of the environment, this gift is not always a reality in most developing communities. The issue of wastewater contamination resulting from rapid population growth, agriculture, industries, and domestic waste has resulted in high levels of pollutants (Beatriz et al., 2018; Rawlins, 2019) in water bodies making them unsafe for consumption. Surface water sources are often highly polluted, and infrastructure to pipe water from fresh, clean sources to arid areas is too costly endeavor. Groundwater is the best resource to provide clean water to most African regions, especially in rural Africa. Groundwater has the benefit of being naturally protected from bacterial contamination and is a reliable source during droughts. Unfortunately, they may be contaminated with heavy metals, and bacteria introduced by leaking septic systems or contaminated wells (Gleick and Pacific Institute for Studies in Development, 2002; Masindi and Foteinis, 2020).
It has been estimated that a minimum of 7.5 liters of water per person per day is required in the home for drinking, preparing food, and personal hygiene, the most basic requirements for water. According to Gleick and Pacific Institute for Studies in Development, (2002), 1.1 billion people around the world lacked access to "improved water supply", and more than 2.4 billion lacked access to "improved sanitation." In Cameroon, diarrheal diseases are the most prevalent waterborne diseases among children aged less than five years. Studies conducted in the city among children aged less than five years showed that the prevalence rate increased from 10.8% in 1998 to 13.1% in 2004.
Agriculture does not only requires large amount of water but also hign amounts of fertilisers. This situation was identified in Buea, an urban community in Cameroon. A study carried out by Toyoh et al. (2017) on the local perceptions on

chemical fertiliser application showed thatmost farmers used fertilisers even though some agrochemical retailers disliked chemical fertilisers because of an inadequate and untimely application by farmers, leading to different health problems (Toyoh et al., 2017). The release of nutrients (nitrogen, phosphorus, and potassium) and agrochemicals from intensive agriculture and animal waste can further accelerate the eutrophication of freshwater and coastal marine ecosystems and increase groundwater pollution. Eutrophication can lead to potentially toxic algal blooms and declines in biodiversity (Bhattacharyya et al., 2020; De Corato, 2020; Sánchez et al., 2017).
Towards remedying the impacts of wastewater in local communities, the Cameroonian government has constructed wastewater treatment station to ensure effluent treatment before discharge in the natural environment. Unortunately, most of them failed to deliver positive results in the later run due to the high nutrient content of wastewaters. This is the case of the Biyemassi II wetland treatment station in Yaounde 1 which initially produced effluent with a 80% average efficiency (TSS: 95%, COD: 92%, turbidity: 90%, color: 88%, BOD_5: 82%, phosphate ions: 55%, ammonium ions 54%, and conductivity 38%). Currently there are days when the system is not functioning correctly, a scenario similar with other ponding treatment systems (Kengne et al., 2014, 2003).
Considering the impacts of the use of synthesis fertilisers and the impacts of wastewater in communities, it was deemed necessary to develop a sustainable wastewater system based on low cost and readily available; materials such as sand, corn cob capable of removing heavy metals and recovering nutrients from wastewater and using it agriculture and irrigation with little impact on the environment. Therefore, the aim of this study is to propose an low cost feasible method to solve an important problem in developing regions.

2. Materials and methods

2.1. Location of the study site and Physico-chemical characterisation influent

Yaounde, Cameroon, Africa, Figure 1, enjoys a typical equatorial Guinean climate characterised by two rain seasons (September to mid-November and mid-March to June) and two dry seasons (mid-November to mid-March and July to August). The annual rainfall is around 1600 mm and daily temperatures vary between 23 and 27 ˚C (Kengne et al., 2003). Its surface area is 304 km² and occupies the Mfoundi Division in the Central Region. The Yaounde metropolis is part of the western sector of the southern Cameroon Plateau, composed of gentle rolling chains of hills and numerous valleys. All these topographic elements depict a contrasted relief.
Samples were collected from a river in Yaounde not far from the Biyemassi appartment buildings. The river was selected because it contained wastewater from households and treated effluent from the wastewater treatment station. In situ parameters such as temperature, pH, and conductivity were measured using a Hanna multimeter. Samples were collected in 1 L containers, stored in an ice cube box to slow down chemical change and 30 L bottles of raw wastewater were then transported in the laboratory for the analysis of physic-chemical parameters.

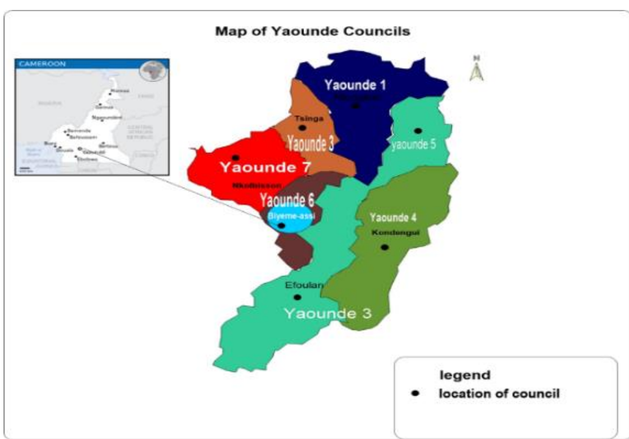

Figure 1: Location of Yaounde subdivisions in Cameroon.

Table 1: Physicochemical characteristics of corn cobs.

Parameter	Unit	Value
Length (average)	cm	7.97±0.3
Diameter (average)	cm	2.54±0.2
pH (average)	-	6.11
Average moisture content	%	58.6
Dry filled weight (average)	g	192
Specific surface area	cm^2/cm^3	1.03
True density	g/cm^3	1.18
Porosity (average)	%	69.8%
C : H : N : S	%	45.3 : 7.1 : 0 : 0

2.2. Treatment and preparation of experimental setup

The samples of raw wastewater collected in 30 L bottles were transported to the laboratory and kept at - 20°C for later use. The treatment process developed in the laboratory for wastewater processing is comprised of the steps described in Figure 2A.

Pre-treatment aimed to remove large particles from the raw wastewater as they can clog and reduce the system's efficiency. In this study, a 300 mm sieve was used to prevent sticks, plastics and other large particles from getting in the treatment system. Further, the wastewater was then channelled into a container serving the role of a sedimentation tank, followed by the filtration steps (Figure 2B). The corn cobs used as filtrating materials were collected from a farm in Biyemassi dried and transformed into charcoal locally in an iron tin. Corn cobs are agricultural waste available in large amounts in Cameroon Central Region.

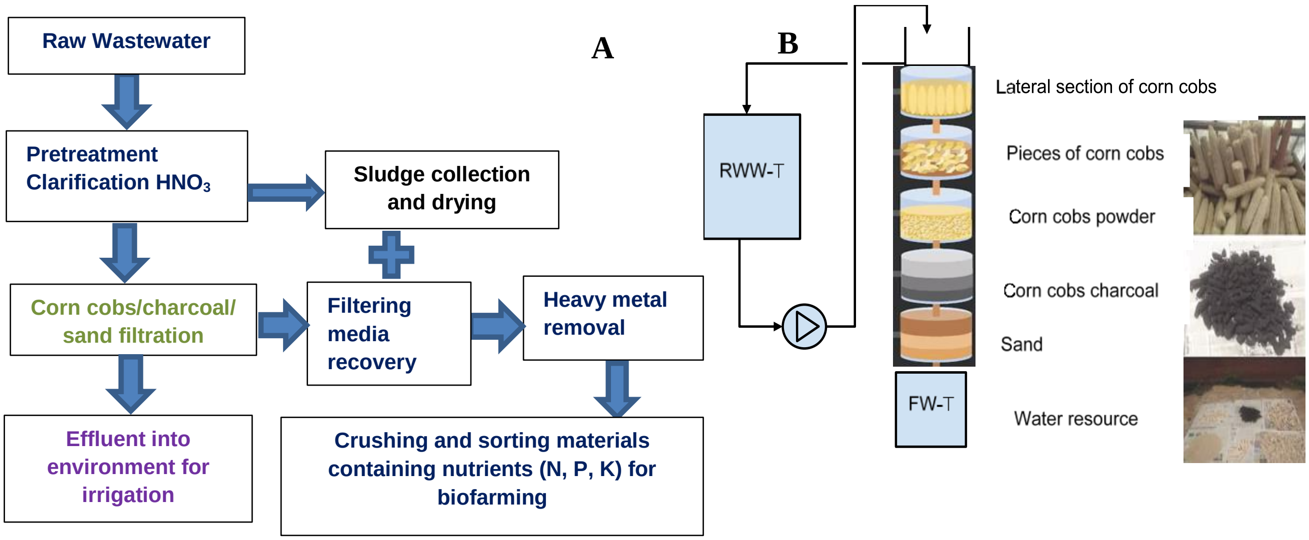

Figure 2: Scheme of the treatment process (A) and experimental setup (B) RWW-T: Raw WasteWater Tank.; FW – T: Filtrated Water- Tank-T for filtering raw wastewater with corn cobs (Eniyavan et al., 2018).

The experimental setup to treat wastewater effluent presented in Figure 2B was modified from Eniyavan (Eniyavan et al., 2018), which used a setup based on leafy husk (cut into 1-2 cm pieces, dried in sunlight and blended into a powder). In our proposed proces, corn cobs are initially dried in an oven and cut into equal-sized pieces having a length (h) and diameter (d) of 7.97 ± 0.30 cm and 2.54 ± 0.20 cm, respectively. They were later washed and dried in an oven for 5 hours. The corn cobs specific surface area was determined by dividing the surface area with a volume of the corn cob, which was 1.03 cm^2/cm^3. Carbonisation of the corn cobs was done locally in an iron drum of 200 L. The corn cobs charcoal was chemically activated using sodium hydroxide solution and thermally activated by the Eniyavan procedure (Eniyavan et al., 2018). In line with Lalita Prasida's method (Eniyavan et al., 2018) the experimental setup sequence included: lateral section of corn cobs, pieces of corn cobs, corn cobs powder, corn cob charcoal, and fine sand filtering steps, Figure 2B.

The following parameters were determined:

$$\% \text{ mass of cob} = \frac{\text{initial mass of cob} - \text{present mass}}{\text{initial mass of cob}} \times 100 \quad (1)$$

$$\% \text{ mass of charcoal} = \frac{\text{present mass of corn cob} - \text{mass of charcoal}}{\text{present mass of corn cob}} \times 100 \quad (2)$$

The flow rate Q (m^3/s) of the river was calculated using the floating method.

$$Q = \frac{V}{t} \quad (3)$$

The adsorbed quantity per unit mass of the solid q (mg/g) and the removal efficiency E (%) were calculated according to Eqs. (41) and (5) (Kengne et al., 2014; Njimou et al., 2016; Yangui et al., 2017):

$$q = \frac{(C_0 - C_e)}{m} V \quad (4)$$

$$E(\%) = \frac{(C_0 - C_e)}{C_e} \times 100 \quad (5)$$

where, C_0 (mg/L) is the concentration of the influent in the liquid phase, C_e (mg/L) the effluent concentration at equilibrium, m (g) the mass of the adsorbent, and V (L) the volume of the wastewater.

3. Results and discussion

3.1. Physicochemical characteristics

Physicochemical characteristics of corn cobs before filtering runs are presented in Table 1, while their characteristics after heavy metals adsorption and matter recovery are presented in Table 2.

Physicochemical parameters of wastewater before and after filtering runs conducted in the laboratory are displayed in Table 3. In line with the above physicochemical properties, raw wastewater composition exceeds the recommended norms. The corn cobs and sand filter system used after pre-treatment permitted the removal of the above composition with percentage efficiency ranging in between 51 and 95% (Table 3). Results show that conductivity is high (1207 µS/cm) due to diverse activities in the appartment buildings Biyemassi but as it passes through the filtration media, its value decreases (589 µS/cm). Cobductivity starts increasing again due to human activities (poultry, pig farming, waste disposal) along the water body.

Table 2: Physicochemical characteristics of corncobs after heavy metals adsorption and matter recovery.

Parameters	Sampling zone		Norms
	before adsorption	*after adsorption*	
pH	7.5	5.5	6.5 -7.5
Temperature (°C)	20.5	21.2	nd
Cu (mg/kg)	8	36	53
Cd (mg/kg)	0.09	4.226	3
Zn (mg/kg)	27.308	159.65	200
Pb (mg/kg)	47.970	40.97	50
N (mg/kg)	1.65	152	0.1-1.8
Total Hydrocarbures (mg/kg)	/	/	nd

Table 3: Physicochemical parameters of wastewater before and after adsorption runs.

Parameters	Sampling zone		Norms	Efficiency E (%)
	Untreated sample	Treated effluent		
pH	7.7	7.8	6-9	/
Temperature (°C)	25.56	25.56	30	/
Turbidity (JTU)	85	4	5	95.3
Conductivity (µS/cm)	1207	589	/	51.20
COD (mg/L)	478.7	53.2	250	60
BDO_5 (mg/L)	139.8	51.9	50	63
TKN (mg/L)	55.8	5.8	≤ 20	89.6
TSS (mg/L)	199.3	20.9	50	89.5
NO_3^- (mg/L)	80	15	/	80
PO_4^{3-} (mg/L)	127	43	/	66.1
Cd^{2+} (mg/L)	1.2	0.4	0.5	66.7
Cu^{2+}(mg/L)	3	0.3	1	90
Pb^{2+} (mg/L)	1.68	0.72	0.5	57

The influent BOD_5 concentration is above the authorised standard (50 mg/L). The COD concentrations recorded are also all above the standard, reflecting a strong presence of organic and biological materials in this polluted water, hence the observed eutrophication phenomenon. The COD concentrations are relatively higher downstream than upstream, reflecting the high degree of pollution happenind downstream due to the inflow of water with high organic content.
The pH values recorded in all the samples are included in the authorised pH range (6 -9). The values of turbidity and suspended matter which are clearly higher in the effluent are brought into the norms after the filtering sequence. The

presence of TKN in this river water can be explained by the fact that people use nitrogen fertilisers to increase their crops, but the system used lead to a decrese of this value into the norms. The results obtained from the effluent and the corn cobs residues collected for biofarming show that they do not contain a high content of heavy metals harmful to the environment and agriculture. Still, some cadmium and zinc traces are present in proportions slightly above the recommended standards.

3.2. Discussion and recommendations

The obtained results showed high removal efficiency for COD, 60% and BOD 63% removal, displaying showing that the proposed filtering system rapidly reduces COD and BOD concentrations. It was observed that this is close correlation with the formation of a slime layer onto the corn cobs filter media. If these norms are followed, raw water quality will contain these effluent composition amounts, not too far from standards.
For the effluent with more than 100% bed volume, the filter bed is saturated with the feed. At this stage, the filtering media in the column was analyzed in order to decide its possible usage as compost material. The results in Table 2 showed the presence of nutrients and some traces of metals in proportions slightly above the recommended standards, showing promising application of this solid as compost. The composting is recognised as a viable alternative and beneficial use of end-product for waste management. Composting is the biological degradation of highly concentrated biodegradable organic wastes in the presence of oxygen (aerobically) to carbon dioxide and water. The final product of composting is a stable humus-like material known as compost (Eniyavan et al., 2018; Vilpas and Santala, 2007).

To obtain the compost from the effluent, saturated filtering material will be removed from the columns, dried, crushed, and sieved using a 40 mm sieve as shown in Figure 3. Compost will be constantly turned using a rake to ensure moisture evaporation and when dried will be stored in bags made from plastics. Its pH, temperature and other necessary parameters will be continuously checked. Water resulting from the treatment system will eventually be used for the irrigation of crops such as cereal and vegetables. Hence a control quality of bio-products will be obtained from the farms.

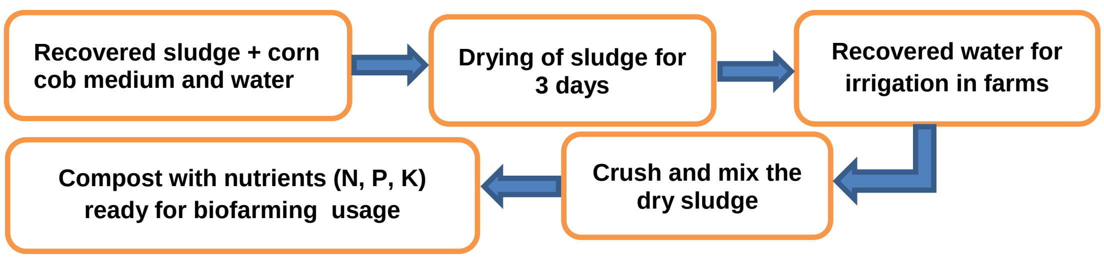

Figure 3:Schematic diagram for nutrients and water recovery for biofarming usage.

4. Conclusions

This study aimed at providing a sustainable wastewater treatment that could ensure water reuse in the sense of recovering nutrients and valorising the water for irrigation. Towards achieving the main goal, wastewater was characterised. The characterisation showed that pH and temperature were within the norms of wastewater in the environment. Unfortunately, other parameters such as BOD, COD, TSS, N and P components were far above admissible values for the environment. Two systems were proposed to remedy the situation: the first for wastewater treatment and recovery for irrigation while the second system aimed at providing a composting system from sludge recovery.
Following initial parameters and studies done in the scientific domain, this work will go a long way to achieve wastewater reuse if present design parameters are implemented in Cameroon's study site. More so, different parameters such as TOC, COD and an ideal rainy season study should be done.
This system has proved that "use of secondary resources" in the treatment of wastewater and the treated wastewater has a wide range of applications as a replacement of water resources for irrigation uses. It is very helpful for people to use this technique to recycle water resources since it is economical and simple in construction. This method is eco-friendly, a facile protocol, thus it is suitable for both developed and developing countries without the use of special equipment and electricity and maintenance cost.

5. Acknowledgements

We wish to acknowledge the support for EXEED workshop funded by the German Academic Exchange Services (DAAD). The authors are grateful for the Fulbright grant PS00301505 that offered data sharing between University of Ngaoundere and Indiana University of Pennsylvania.

6. References

Beatriz, E.D., Molnar, B.E., Griffith, J.L., and Salhi, C. (2018). Urban-rural disparity and urban population growth: A multilevel analysis of under-5 mortality in 30 sub-Saharan African countries. Health Place *52*, 196–204.

Bhattacharyya, C., Roy, R., Tribedi, P., Ghosh, A., and Ghosh, A. (2020). Chapter 11 - Biofertilizers as substitute to commercial agrochemicals. In Agrochemicals Detection, Treatment and Remediation, M.N.V. Prasad, ed. (Butterworth-Heinemann), pp. 263–290.

De Corato, U. (2020). Agricultural waste recycling in horticultural intensive farming systems by on-farm composting and compost-based tea application improves soil quality and plant health: A review under the perspective of a circular economy. Sci. Total Environ. *738*, 139840.

Eniyavan, S.A., Gowtham, J., Guruprasath, V., Vijay, H.K.U., and Thenmozhi, R. (2018). Greywater Treatment using Corncob. IJSRD - Int. J. Sci. Res. Dev. 1181–1184.

Gleick, P.H., and Pacific Institute for Studies in Development, E., and Security (2002). Dirty-water: estimated deaths from water-related diseases 2000-2020 (Oakland, CA: Pacific Institute for Studies in Development, Environment, and Security).

Kengne, E.S., Kengne, I.M., Nzouebet, W.A.L., Akoa, A., Viet, H.N., and Strande, L. (2014). Performance of vertical flow constructed wetlands for faecal sludge drying bed leachate: Effect of hydraulic loading. Ecol. Eng. *71*, 384–393.

Kengne, I.M., Brissaud, F., Akoa, A., Eteme, R.A., Nya, J., Ndikefor, A., and Fonkou, T. (2003). Mosquito development in a macrophyte-based wastewater treatment plant in Cameroon (Central Africa). Ecol. Eng. *21*, 53–61.

Masindi, V., and Foteinis, S. (2020). Groundwater contamination in sub-Saharan Africa: implication to groundwater protection in developing countries. Clean. Eng. Technol. 100038.

Njimou, J.R., Măicăneanu, A., Indolean, C., Nanseu-Njiki, C.P., and Ngameni, E. (2016). Removal of Cd (II) from synthetic wastewater by alginate - Ayous sawdust (*Triplochiton scleroxylon*) composite material. Env. Technol *37*, 1369–1381.

Rawlins, J. (2019). Political economy of water reallocation in South Africa: Insights from the Western Cape water crisis. Water Secur. *6*, 100029.

Sánchez, Ó.J., Ospina, D.A., and Montoya, S. (2017). Compost supplementation with nutrients and microorganisms in composting process. Waste Manag. *69*, 136–153.

Singh, A. (2013). Nitrate and phosphate contamination in water and possible remedial measures. pp. 44–56.

Toyoh, L., Kiyo, L., and Nkemnyi, M.F. (2017). Chemical fertilizer application and farmers perception on food safety in Buea, Cameroon. Agric. Sci. Res. J. *6*, 287–295.

Vilpas, R., and Santala, E. (2007). Comparison of the nutrient removal efficiency of onsite wastewater treatments systems: applications of conventional sand filters and sequencing batch reactors (SBR). Water Sci. Technol. *55*, 109–117.

Yangui, A., Njimou, J.R., Cicci, A., Bravi, M., Abderrabba, M., and Chianese, A. (2017). Competitive adsorption, selectivity and separation of valuable hydroxytyrosol and toxic phenol from olive mill wastewater. J. Environ. Chem. Eng. *5*, 3581–3589.