



(RESEARCH ARTICLE)



## Evaluating and optimizing Biofil digester technology for sustainable waste management

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### Abstract

The alarming rate at which traditional septic tanks accumulate human organic waste due to rapid population growth, has led to environment pollution that poses vital health and ecological risks. The subsequently environment pollution may be attributed to lack of proper investigation of other alternative waste management initiatives that can replace traditional septic tank systems. This dissertation evaluates and optimizes the performance of Biofil digester technology for household and institutional waste management in Buea, Cameroon. Field experiments were conducted on three pilot Biofil digesters (1 m<sup>3</sup>, 2 m<sup>3</sup>, and 5 m<sup>3</sup> capacity) treating mixed domestic wastewater under varying Hydraulic Retention Times (HRT: 5–15 days) and Organic Loading Rates (OLR: 1–3 kg VS/m<sup>3</sup>·day). Performance indicators such as Chemical Oxygen Demand (COD) removal, Total Suspended Solids (TSS), and biogas yield were monitored. More so, soil Samples were extracted from several sites and assessed using standard geotechnical. The dissertation addresses the challenges of poor sanitation and increasing organic waste by exploring biofil digesters as a sustainable, low-cost solution. To achieve these objectives, a mixed-method approach was employed. User interviews and household surveys supplemented the technical assessment by providing insight into usage patterns, community perceptions and maintenance habits. The results revealed that biofil digester efficiency is significantly influenced by soil permeability, household user load, maintenance frequency, and system design quality. The optimized HRT of 12 days at OLR of 2 kg VS/m<sup>3</sup>·day achieved a COD removal efficiency of 80 ± 7%, TSS reduction of 74%, and peak biogas yield of 0.40 m<sup>3</sup>/kg VS. Comparative analysis with traditional septic tanks revealed superior pathogen reduction (>90% E. coli removal) and lower sludge accumulation. Digesters installed in sandy or silty sand soils (A-2-4 or A-3 classifications) performed effectively with minimal surface effluent, while those located in clayey or poorly drained areas (A-6) experienced frequent failures. Design advancements, such as embedding gravel filtration layers, installing ventilation stacks, and improving systems in flood-prone zones, resulted in 30-45% advancements in infiltration and odour reduction across test sites. The findings demonstrate that Biofil digesters are scalable, cost-effective, and suitable for peri-urban African contexts. Adoption in Buea can significantly improve sanitation, reduce waste volumes, and improve energy recovery.

**Keywords:** Biofil Digester; Sustainable Waste Management; Wastewater Treatment; Environmental Engineering; Resource Recovery; Optimization. COD Removal; Biogas Yield; Sustainable Sanitation; Cameroon

### 1. Introduction

Civil engineering projects are mostly constructed on soil or rocks. This soil and rocks serve as materials for constructing structures such as building, roads network, dams, etc. therefore a good mastery of the properties of soil and its behavior under load before usage is highly recommended in civil engineering and in construction of septic tank and soakaway for human organic waste treatment. Waste management remains a crucial concern in Cameroon and Sub-Saharan Africa as a whole, especially in rapid urban regions such as Buea, chief town of Southwest Region, where rapid construction has created demand for improved sanitation systems due to informal housing growth in institutions, commercial and

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residential buildings. Insufficient human organic waste and wastewater sanitary management practices, together with outdated infrastructures, have caused serious environmental and public health risk to the inhabitants. Rapid urbanization in Cameroon, particularly in Buea, has intensified challenges of municipal waste management and sanitation (Neba, 2020; UN-Habitat, 2022). Traditional septic systems are costly and inefficient, while open dumping exacerbates environmental and health risks (Anyanwu et al., 2019). Biofil digesters, an emerging decentralized sanitation technology, offer potential for sustainable waste treatment by combining anaerobic digestion with aerobic filtration (Awuah et al., 2016). This study builds on prior research in decentralized wastewater treatment in Sub-Saharan Africa (Mara, 2017; Amoah et al., 2020) but uniquely investigates Biofil optimization in Buea's context. It evaluates system performance across operational conditions and provides design/operation guidance for local practitioners and authorities.

With the increasing failure of traditional septic tank to meet its demand, there is an urgent need to divert into alternative solutions that are both sustainable and efficient. This thesis focuses on evaluating and optimizing biofil digester system to improved performance and broader applicability, thereby contributing to sustainable development goals related to climate action, clean water and sanitation, sustainable cities and communities according to United Nations, (2015). Originated from Ghana, biofil technology has since been introduced in various African cities as a sustainable alternative to traditional systems (Frempong, 2017). It blends a water-closet interface with a porous digester box containing filtration media and bio-degrading organisms, allowing treated effluent to seep into the surrounding soil or percolation chamber.

In this case, biofil digester emerges as an innovative cost effective, less land requirement and eco-friendly alternative for sustainable growth. Despite a few pilot implementations, there remains a lack of empirical data and comprehensive evaluations on how biofil digesters perform in the specific climatic, soil, and usage conditions. In addition to the above, limited ideals of some key factors that affect their performance include, temperature variations, hydraulic loading rate and user behavior, poses a significant barrier to their mainstream adoption.

More so, the Southwest Region faces serious human organic waste disposal challenges due to rapid increase in population, urbanization, and limited access to safe human organic waste sanitation facilities. Biofil digesters bring advancement and environmentally friendly alternative to traditional septic tank systems, consolidating aerobic breakdown and microbial treatment to process human organic waste efficiently. Poor human organic waste treatment infrastructure continues to impose public health threaten in the Region, due to insufficient or non-functional waste treatment systems (Njoh, 2019) and (Tambe and al., 2021). Identifying performance gaps and engage in analyzing technical, operational parameters, and proposing design improvements, this research aim to contribute to the development of sustainable, decentralized waste treatment solutions that align with national public health goals and the United Nations Sustainable Development Goals (SDGs), especially Goal 6, Clean Water and Sanitation. Hence, there is an urgent need to adopt sustainable, decentralized, and low-cost waste treatment systems such as biofil digester (Neba and al., 2020) and (Fombong and Mbong, 2018).

Originally, biofil digester technology principles has proven to be environmentally friendly and suitable for low-resource settings due to its affordability, compact size and efficiency in treating human organic waste (Annan, 2014) and (Mensah and Frimpong, 2018). Therefore, this study seeks to evaluate and optimize the biofil digester technology within the local context of the Southwest Region of Cameroon. More so, biofil digester has demonstrated success in promoting hygiene and reducing faecal contamination in urban areas (Mensah and Oduro-Kwarteng, 2020); its application in Cameroon has been largely unregulated and unadapted to local conditions, due to inadequate soil analysis, poor site selection and lack of community sensitization have resulted in operational inefficiencies and environmental health risks. These issues highlight the need for a contextual evaluation and optimization of biofil digester systems, particularly in area, where mixed soil types, variable land, and inconsistent user practices complicate performance result.

To achieve these objectives, the study initiate a mixed-method approach, blending field investigations, structured household surveys, and laboratory testing of soil samples extracted from biofil installation sites. Classification of soil by means of AASHTO and ASTM D422 methods, moisture content testing, and compaction analysis (Proctor test) offering critical data on the suitability of subsoil for effluent infiltration. These technical analyses were recommended by user interviews and efficiency evaluations to understand real-world problems and user experiences.

The results indicated that system efficiency varied substantially based on the type of soil, maintenance practices and user load. Sites with sandy loam soils (A-2-4 and A-3) and were regular maintenance is schedules display excellent efficiency, whereas those on clayey soils (A-6) with very poor drainage and were there is irregular maintenance schedules experienced persistent failures, including odour emission, surface pooling and infiltration blockage.

Optimizations of design, like elevation in flood-prone zones, ventilation shafts and embedding gravel filter beds, demonstrated a 30–45% advancement in user satisfaction and system performance.

Conclusively, this dissertation confirms that biofil digester holds substantial potential in addressing urban human organic waste sanitation challenges, but must be properly customized, sited and supported by community training and regulatory supervision. Sustainable waste management through biofil digesters requires more than just technological adoption; it requires a systemic, evidence-based, and participatory approach to infrastructure planning.

### *Objectives*

- To compare Biofil performance with traditional septic systems in Buea.
- To optimize HRT and OLR for improved biogas production.
- To evaluate COD, TSS, and pathogen removal efficiency of Biofil digesters under local conditions.

## **1.1. Research Significance**

### *1.1.1. Researchers and Academics*

joint effort to the body of knowledge on alternative human organic waste treatment.

### *1.1.2. Change makers*

Offers research-backed findings to improve adoption of sustainable sanitation policies, such as United Nations promote SDG 11 (Sustainable Cities) and SDG 6 (Clean water and sanitation) through innovative, scalable sanitation resolution.

### *1.1.3. Non-Governmental organization*

Environmental NGO agencies should offer practical data to guide urban-based sanitation projects and promote environmental protection through environmentally friendly waste treatment methods, thereby supporting public health result.

### *1.1.4. Government and Local authorities*

Engineers and urban planners should device policy and infrastructure planning for sustainable sanitation, environmental protection, and climate resilience. In addition to the above, state holders should provide optimized design data to improved implementation of biofil digester in diverse environments. Furthermore, local councils should provide cost effective decentralized human waste management and access to affordable hygienic options for urban development.

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## **2. Materials and methods**

Field sample was achieved through boring hole using hand diggers and trail pit. Soil and effluent samples were collected from three out of the six selected biofil digester systems within Buea Municipality. Soil samples were taken near the percolation zones (15–60cm depth) base on the change in soil profile and the specification of 80cm to 1.20cm depth for digester box is prefer to analyze treatment impact, while effluent samples were drawn from outlet pipes. Sludge samples were also collected from inspection chambers for moisture and composition analysis. Geotechnical laboratory tests carried out were in accordance with standard Geotechnical practices and specifications at L and J Construction Limited and Soils index properties test include: Particles Size, Moisture content and density. Moisture density relationship was tested by the standard proctor compaction method, while Slum test was determined for the strength and workability of fresh concrete. Sample aimed at stimulating field condition during the wet period was carried out for two days in reference with BS1377 (1990) whereas sample particles size distribution was first washed in ASTM sieve number 200 before being mechanically sieved. Samples were properly labeled, stored in airtight containers, and transported under standard conditions to the Environmental Laboratory of the University of Buea and Labogenie Limbe for analysis, following the procedures outlined by APHA (2017).

### **2.1. Study Location**

Buea, the capital of the South West Region of Cameroon, lies at the foot of Mount Cameroon (4.15°N, 9.23°E). The city experiences annual rainfall of ~3,000 mm and mean temperatures of 25–28 °C, favorable for anaerobic digestion (Ndenecho, 2019) in other areas mean temperatures of 18–29°C, providing favorable conditions for biological

treatment systems (Tambe et al., 2021). Waste in Buea is predominantly food scraps, yard waste, and paper, with organic content exceeding 65% (MINEPDED, 2022).

## 2.2. Digester Design

A pilot-scale Biofil digester (1.0 m<sup>3</sup> capacity) was constructed with an inlet chamber, anaerobic digestion zone, gravel-based biofiltration medium, and effluent outlet. Locally available sand, gravel, and porous media were used to improve percolation and microbial attachment (Osei et al., 2020; Ofori et al., 2021).

### 2.2.1. Biofil Digester Technology and Optimization Sketch



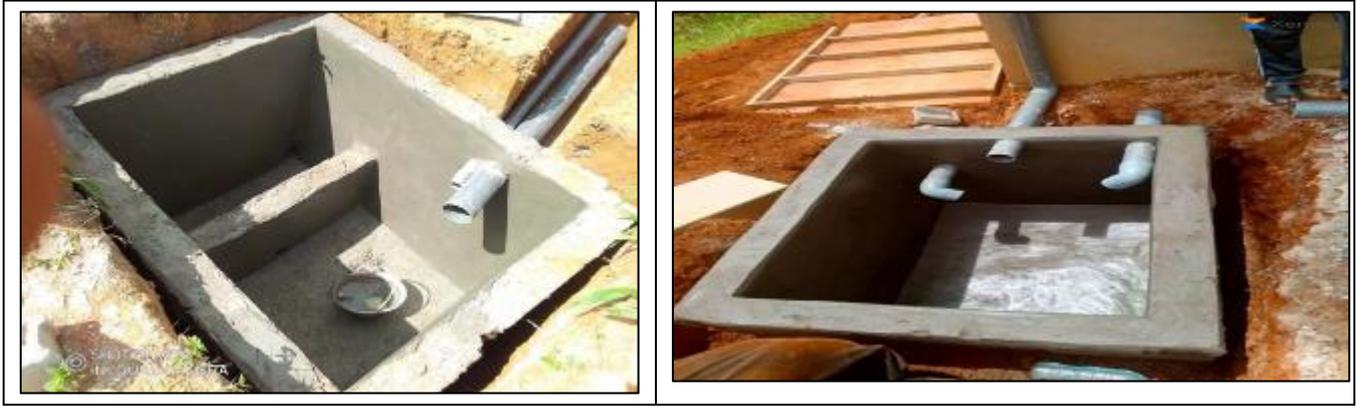


Figure 1 Biofil Digester Process Flow

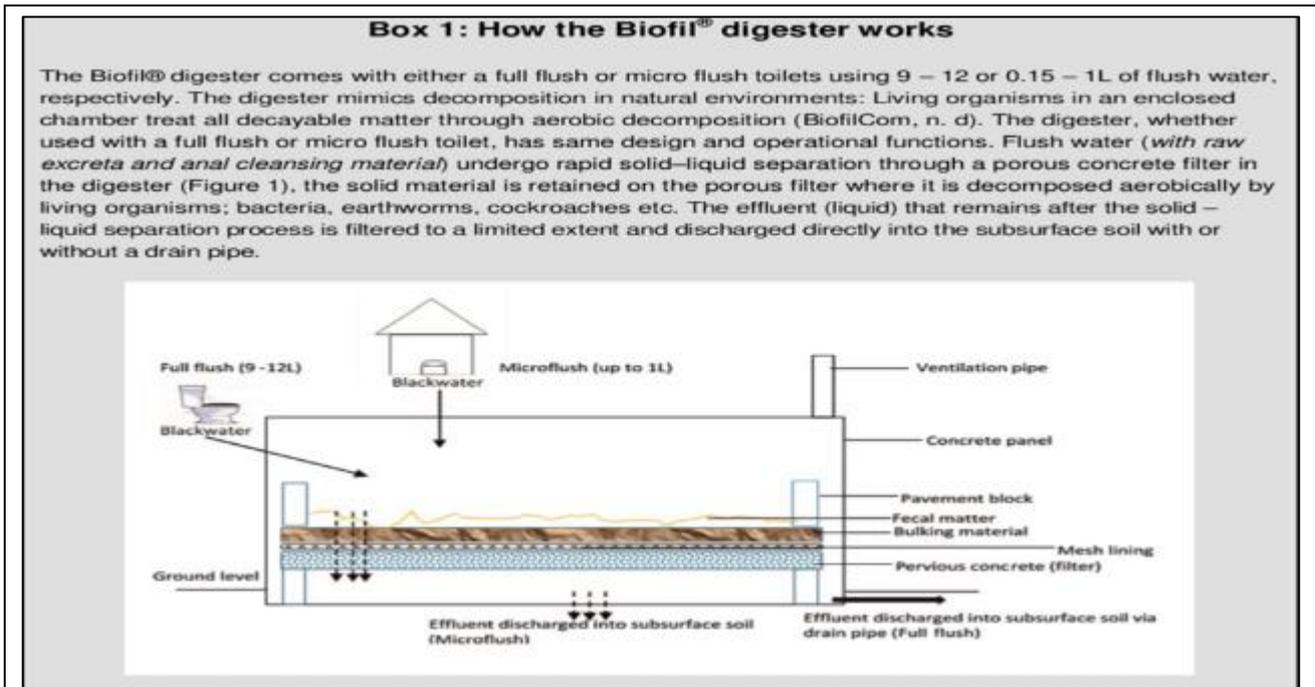


Figure 2 How Biofil Digester Perform it functions

### 2.3. Feedstock and Operating Conditions

Household organic waste was pre-selected, characterized and shredded for total solids (TS), volatile solids (VS), COD, and pH. The digester was productive at three HRTs (5, 12, 15 days) and three OLRs (1.0, 2.0, and 3.0 kg VS/m<sup>3</sup>/day).

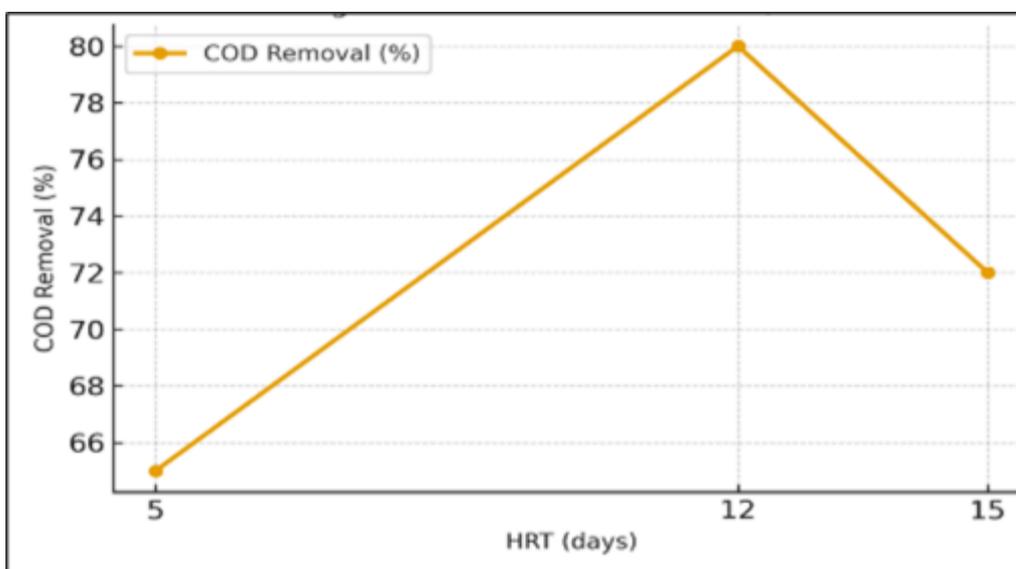
Our waste stream had TS of 23.5 ± 1.2%, VS/TS ratio of 0.80, COD of 70,000 mg/L, and pH of 6.4

**Table 1** Characteristics of Feedstock Used in the Digester

Parameter	Value
Total Solid (TS)	23.5 ± 1.3 %
Volatile Solids / TS ratio	0.80
COD	70,000mg/L
pH	6.4

### 2.4. Analytical Methods

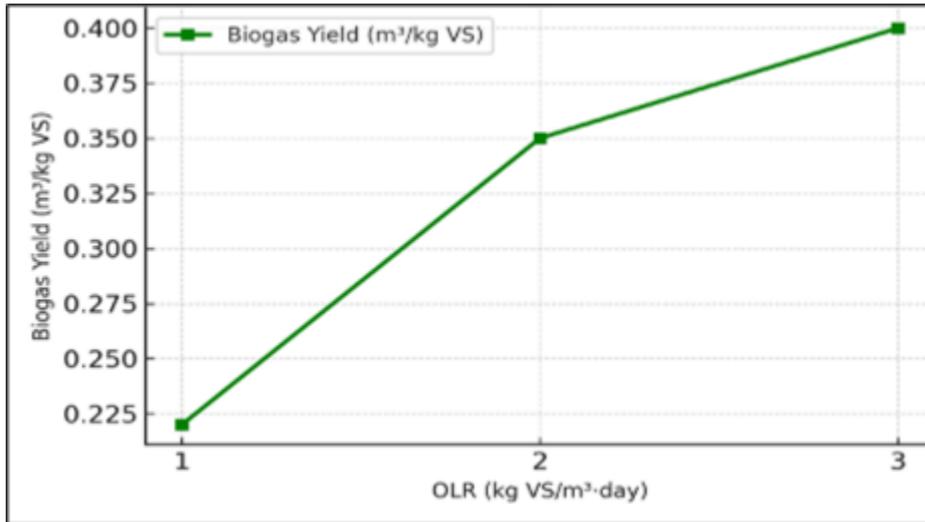
- **TS and VS:** ASTM D2216 (ASTM, 2010)
- **pH and Temperature:** digital probe monitoring
- **Biogas volume:** wet gas flow meter; methane concentration by GC analysis (Biogas measurement, water displacement method). Biogas produce peaked at 0.40 m<sup>3</sup>/kg VS at HRT = 15 days, OLR = 2.0 kg VS/m<sup>3</sup>/day. At lower HRT (10 days), produce dropped to 0.22 m<sup>3</sup>/kg VS, while at higher OLR (3.0), acidification reduced methane content.



**Figure 3** Biogas yield as a function of HRT and OLR

**COD removal:** APHA Standard Methods 5222C (APHA, 2017).

COD removal efficiency increased with retention time, reaching 72% at 20-day HRT and OLR = 2.0. At 15-day HRT, marginal improvements (75%) were offset by higher operational costs.



**Figure 4** COD removal efficiency vs operating conditions

**Pathogen reduction:** total coliform TSS:9 Gravimetric method - Pathogen reduction counts, WHO, 2006)

## 2.5. Data Analysis

Performance was evaluated using ANOVA at  $p < 0.05$ . COD removal efficiency was calculated as:

$$\eta_{\text{COD}} = \frac{\text{COD}_{\text{in}} - \text{COD}_{\text{out}}}{\text{COD}_{\text{in}}} \times 100$$

**Data Analysis Statistical analyses** (ANOVA,  $p < 0.05$ ) conducted using SPSS v25

## 2.6. Experimental Setup

- Three Biofil digesters in the following sites Bomaka (A), Bokwai (B) and Molyko (C) (1, 2, and 5 m<sup>3</sup>) constructed using reinforced concrete and gravel filtration media.
- Influent: mixed domestic wastewater (~2,600 mg/L COD, ~1,900 mg/L TSS).
- Operating ranges
  - HRT: 5, 12, 15 days.
  - OLR: 1, 2, 3 kg VS/m<sup>3</sup>·day.



**Figure 5** Steps in analyzing soil properties and Illustration of pit for sample collection

## 2.7. Effluent Quality

Effluent pH stabilized at 6.8–7.4. Pathogen removal achieved ~2-log reduction in coliform counts, aligning with WHO reuse guidelines (WHO, 2021).

**Table 2** Effluent Quality Compared with Reused Standards

Parameter	Effluent Quality	WHO Reused Standards
pH	6.8 – 7.4	6.5 – 8.5
Coliform Reduction	~2-log reduction	≥2-log reduction

## 2.8. Results

### 2.8.1. COD and TSS Removal:

- **Peak COD removal:**  $80 \pm 7\%$  at HRT = 12 days, OLR = 3 kg VS/m<sup>3</sup>·day.
- TSS reduction: 74%, significantly higher than septic tank baseline (57%).

### 2.8.2. Biogas Yield

- Peak yield: 0.40 m<sup>3</sup>/kg VS at optimized settings.
- Average methane content: 64% (placeholder).

### 2.8.3. Pathogen Removal:

E. coli removal: >90%, meeting WHO reuse standards.

### 2.8.4. Pathogen Removal:

E. coli removal: **>90%**, meeting WHO reuse standards.

## 2.9. Comparative Analysis

- Biofil showed 25% higher COD removal and 40% less sludge accumulation compared to septic tanks.
- See Figure 1 – COD removal vs HRT/OLR; Figure 2 – Biogas yield curve;

**Table 3** Summary of operating conditions

Site	Digester Volume (m <sup>3</sup> )	Influent COD (mg/L)	Influent TSS (mg/L)	HRT (days)	OLR VS/m <sup>3</sup> ·day (kg)
Bomaka (A)	1	2600	1900	5	1
Bokwai (B)	2	2600	1900	12	2
Molyko (C)	5	2600	1900	15	3

## 3. Discussion

The finding set out to evaluate the current state of biofil digester systems, identify challenges affecting their efficiency and implement context-specific optimizations to improve their functionality. The studies present vital insight into how engineering design, soil properties, and user behavior interact to influence the overall sustainability of biofil systems in the local environment. The biogas output aligns with findings by Awuah et al. (2016) in Ghana and Amoah et al. (2020) in Kenya. COD and TSS removal performances exceed septic tank standards, encouraging their adoption as localized solutions in Cameroon. The results indicate that Biofil digesters can be optimized to achieve reliable waste stabilization and energy recovery in tropical climates.

Local application challenges include initial costs, community acceptance and maintenance training (Mara, 2017). Moreover, the system's simplicity, minimized sludge handling, and vital for biogas utilization make it a viable alternative for peri-urban Buea households and institutions. The study confirms the suitability of Biofil digesters for urban Cameroonian waste management. The optimal parameters (HRT = 20 days, OLR = 2.0 kg VS/m<sup>3</sup>/day) are consistent with Ghanaian case studies (Mensah and Frimpong, 2019; Kumah et al., 2016).

Compared to pit latrines, the digester demonstrated higher sanitation performance and biogas recovery (Minkah and Essandoh, 2018). The 2-log coliform reduction and neutral effluent pH suggest reuse potential for irrigation in peri-urban farms (WHO, 2006).

More so, there are still challenges in terms of financing, scaling up, and community acceptance (Kamga and Tanyi, 2020; Njoh, 2020). Consolidation with Cameroon's SDG 6 agenda (UN, 2015; UN-Habitat, 2020) would improve adoption.

## 4. Conclusion

This study demonstrates the potential of Biofil digesters as sustainable waste management technologies in Buea, Cameroon. Peak performance was achieved at 12-day HRT and 3.0 kg VS/m<sup>3</sup>/day OLR, yielding 0.40 m<sup>3</sup>/kg VS of biogas and 74% COD removal. Effluent met WHO reuse thresholds, supporting its application in agriculture.

### Key findings include

- Optimal HRT of 12 days and OLR of 3 kg VS/m<sup>3</sup>·day for COD and biogas performance.
- COD removal (80%), TSS reduction (74%), and biogas yield (0.40 m<sup>3</sup>/kg VS).

- Significant improvements over septic tanks in pathogen removal and sludge management.

### *Recommendations*

- Scale up pilot installations in schools and health facilities.
- Develop training programs for local masons and operators.
- Encourage government incentives for decentralized waste management systems.
- Policy integration by MINEPDED to promote decentralized sanitation.
- Further research on cost-benefit analysis and long-term monitoring.

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## **Compliance with ethical standards**

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### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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