J.Natn.Sci.Foundation Sri Lanka 2025 53 (3): 283 - 292
DOI: http://dx.doi.org/10.4038/jnsfsr.v53i3.12089

RESEARCH ARTICLE

Environmental Science

Performance evaluation of a lab-scale upflow anaerobic sludge blanket (UASB) reactor for landfill leachate treatment under ambient temperature conditions

HPDU Iroshani[1], PG Rathnasiri[2], Wasala MKRTW Bandara[3*], and PHGAD De Silva[4]
[1] *Sri Lanka Institute of Advanced Technical Education, Colombo, Sri Lanka.*
[2] *Department of Chemical and Process Engineering, Faculty of Engineering, University of Moratuwa, Moratuwa, Sri Lanka.*
[3] *Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Sri Lanka.*
[4] *DAN Structures Pty Ltd, 7 Pilgrim Ct, Ringwood 3134 VIC. Australia*

Submitted: 12 March 2024; Revised: 10 August 2025; Accepted: 14 August 2025

This study presents a comprehensive performance evaluation of a lab-scale upflow anaerobic sludge blanket (UASB) reactor for treating landfill leachate under ambient temperature conditions (28 - 32°C), representative of tropical climates. The reactor was operated continuously for 94 days with real landfill leachate, investigating the system's treatment efficiency across varying hydraulic retention times (HRTs) from 6 to 10 h. Key performance indicators, including organic matter removal, biogas production, and heavy metal reduction, were systematically analyzed. The results demonstrated optimal treatment performance at 6 h HRT, achieving 64 ± 1% COD removal efficiency with a concomitant high methane yield of 86.1 ± 1.1% in the produced biogas. The reactor maintained stable operational conditions, with pH in the range 6.2 - 7.5 and oxidation-reduction potential consistently below -200 mV, confirming effective anaerobic digestion under ambient temperature conditions. Heavy metal removal efficiencies varied significantly, with maximum removal observed for lead (55 ± 1%) and chromium (47 ± 1%), while suspended solids removal reached 66% for total suspended solids (TSS) and and 29% for volatile suspended solids (VSS). The study provides critical insights into the applicability of UASB technology for landfill leachate treatment in tropical regions, highlighting both its strengths in organic load reduction and limitations in comprehensive contaminant removal under ambient temperature operation. The findings contribute to the development of sustainable, climate-appropriate leachate treatment solutions for regions with limited resources.

Keywords: Ambient temperature treatment, anaerobic digestion, landfill leachate, tropical climate, UASB reactor, wastewater treatment.

INTRODUCTION

Sanitary landfilling remains one of the most widely adopted methods for municipal solid waste (MSW) disposal due to its economic feasibility and environmental advantages when properly managed (Sewwandi *et al.*, 2011). However, a critical environmental concern associated with landfills is the generation of leachate, a highly contaminated wastewater that results from the percolation of rainwater through degrading solid waste. Leachate, characterized by high concentrations of organic matter, heavy metals, ammonium, and other pollutants, poses a significant threat to groundwater and adjacent surface water bodies. This risk is particularly pronounced in developing nations. For instance, studies in Sri Lanka have highlighted the substantial risk of contamination of soil and water bodies like rivers (Shayan *et al.*, 2020) by heavy metals from open dumpsites (Sewwandi *et al.*, 2011). As a developing country, Sri Lanka faces the persistent challenge of implementing a comprehensive solid waste management strategy that includes effective leachate treatment systems.

* Corresponding author (wasala@cee.ruh.ac.lk; https://orcid.org/0000-0001-8403-386X)

The physicochemical characteristics of leachate are highly variable and are typically assessed using parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), pH, total suspended solids (TSS), total kjeldahl nitrogen (TKN), and total phosphorus (TP). This variability is influenced by several factors, including landfill age, climatic and seasonal variations, and the composition of the deposited waste (Ifeanyichukwu, 2008). Notably, the age of a landfill can lead to significant variations in leachate composition, which in turn complicates the selection and design of treatment technologies (Baig *et al*., 1999).

The treatment of landfill leachate is notoriously difficult due to the presence of high concentrations of organic, inorganic, and inhibitory compounds, particularly ammonia. High ammonia levels can severely impede biological treatment processes. For example, Yuzer *et al.* (2012) demonstrated that increasing ammonia concentrations in an anaerobic digestion system caused COD and BOD removal efficiencies to plummet from 95% to as low as 15%.

Various biological treatment methods, including aerobic, anaerobic, and hybrid systems, have been investigated for leachate management. Anaerobic processes are often considered more effective for high-strength wastewater streams like leachate, owing to their lower operational costs and significantly lower sludge production, approximately 5–10% of that from aerobic systems (Karthikeyan & Kandasamy, 2009). To overcome the limitations of conventional anaerobic reactors, high-rate configurations have been developed. Among these, the up-flow anaerobic sludge blanket (UASB) reactor is a promising technology for treating high-strength wastewater. The UASB system utilizes a suspended blanket of granular sludge to efficiently entrap and degrade contaminants.

According to established design principles for high-rate anaerobic systems, UASB reactors are engineered to operate within specific performance envelopes. As detailed in seminal texts like Metcalf & Eddy's *Wastewater Engineering: Treatment and Reuse* (2004), typical design norms for treating high-strength industrial wastewaters under mesophilic conditions include organic loading rates (OLRs) ranging from 10 to 25 g-COD/L/d and expected COD removal efficiencies of 70–85%. Performance in tropical climates is often comparable, though it can be influenced by the unique characteristics of the waste stream, such as the high proportion of refractory organics found in mature leachate (Kurniawan *et al*., 2006). For instance, research on UASB treatment of landfill leachate in Brazil reported COD removals of 65-80% at OLRs between 8 and 16 g-COD/L/d (de Lemos Chernicharo, 2007), while studies in India on stabilized leachate showed efficiencies closer to 55-65% (Tatoulis *et al*., 2017). These benchmarks provide a critical framework for evaluating the feasibility and efficacy of new applications.

In tropical regions, ambient temperature is a crucial parameter affecting the efficiency of anaerobic treatment (Wasala *et al*., 2024). While optimal performance is often achieved under thermophilic conditions (45 °C - 60 °C), this would necessitate heating the wastewater, thereby incurring additional operational costs (Wasala *et al*., 2011). Sri Lanka's tropical climate provides an average ambient temperature between 20 °C and 35 °C, which aligns with the mesophilic range for anaerobic digestion. This presents an opportunity to develop cost-effective treatment systems that operate efficiently without external heating.

Building upon this premise, preliminary research at the University of Ruhuna, Sri Lanka, developed a lab-scale UASB reactor (Wasala *et al*., 2024) and demonstrated its potential for treating synthetic leachate under ambient temperatures, achieving an 80% COD removal efficiency (Fonseka *et al*., 2015). The present study is a direct continuation of this work, aiming to validate the applicability of the UASB reactor for treating real-world leachate. The leachate for this investigation is sourced from a 20-year-old municipal open dumpsite located near a natural water stream in Sri Lanka.

Given that treatment efficiencies are highly dependent on local climatic conditions and that there is a documented lack of appropriate on-site leachate treatment methods in Sri Lanka (Sewwandi *et al*., 2011), it is imperative to investigate solutions that are both cost-effective and suitable for the region. Therefore, the objective of this research is to optimize the operational parameters of a UASB reactor for the treatment of mature landfill leachate under the ambient tropical climatic conditions of Sri Lanka and to benchmark its performance against both established design norms and findings from similar research.

MATERIALS AND METHODS

Experimental setup and operational conditions

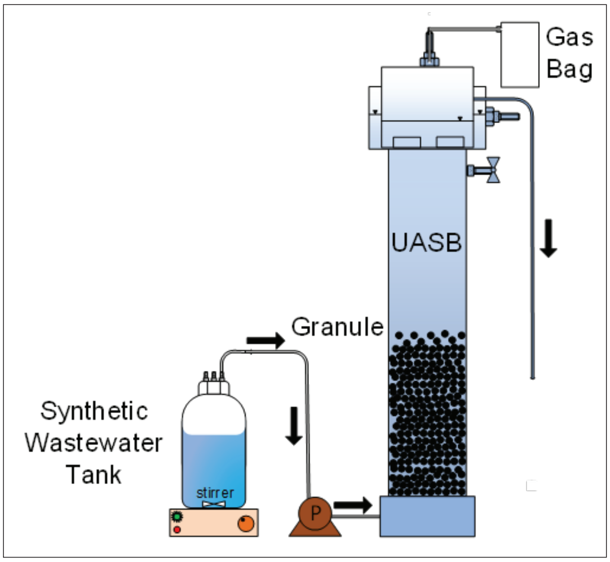

Figure 1: Schematic diagram of the UASB reactor

The experiment was conducted in a custom-fabricated, lab-scale up-flow anaerobic sludge blanket (UASB) reactor, constructed from perspex with a height of 60 cm, an internal diameter of 10 cm, and a working volume of 5 L (Figure 1). To ensure uniform influent distribution, the base of the reactor was fitted with a conical funnel leading to the inlet valve. Leachate was introduced from the bottom, while the top of the reactor was equipped with two separate valves for the collection of headspace biogas and the withdrawal of treated effluent. An additional sampling port on the reactor body allowed for the collection of mixed liquor samples during operation. To minimize the microbial lag phase, the reactor was inoculated with 1 L of anaerobic granular sludge, characterized by a total solids (TS) concentration of 29 g/L and a volatile solids (VS) concentration of 23 g/L. A variable displacement peristaltic pump (Biobase, Model BT 600M, China) continuously delivered the raw leachate influent. The pump's flow rate was maintained between 8.5 and 14 mL/min to achieve hydraulic retention times (HRT) ranging from 6 to 10 h. The experiment was operated continuously over a period of 94 days. Raw leachate was sourced from a local municipal landfill on a weekly basis and stored in a plastic feed reservoir connected to the pump inlet.

Analytical methods

A comprehensive suite of analytical methods was employed to monitor reactor performance and characterize the leachate. BOD was measured using the BOD Apparatus, and COD was quantified using the Hach method with a DR 1900-01 spectrophotometer. Key electrochemical parameters, including pH and oxidation-reduction potential (ORP), were continuously monitored using a PHC301 pH electrode and an MTC101 ORP probe, respectively, while temperature was measured with a standard laboratory thermometer. The concentrations of selected heavy metals (Pb, Hg, Cr, Cd, As, and Fe) were determined via inductively coupled plasma optical emission spectroscopy (ICP-OES).

Biogas composition (CH_4, CO_2, N_2, O_2, and H_2) in the reactor headspace was analyzed using a gas chromatograph (Gasboard 3200L, Hubei-Ruiyi Instrument Co. Ltd.) (Wasala *et al*., 2024). The daily biogas production volume was quantified by collecting the cumulative gas in a sealed bag and measuring its volume via the water displacement method. To ensure data robustness, the average gas production rate for each HRT was calculated from six replicate 24 h measurements. A consistent water column was used for all volumetric determinations to minimize measurement errors associated with gas dissolution.

Finally, total suspended solids (TSS) and volatile suspended solids (VSS) were determined gravimetrically in accordance with standard methods.

RESULTS AND DISCUSSION

Key operational parameters, including pH, temperature, and ORP, were monitored daily to assess the stability of the reactor environment. As illustrated in Figure 2, the pH of the influent leachate varied between 7.5 and 8.5, while the internal pH of the UASB reactor was consistently maintained within a stable range of 7.0 to 7.5.

This operational pH is significant, as it is directly influenced by the concentrations of ammonium ions and volatile fatty acids. The observed range is highly favorable for anaerobic processes, particularly for methanogenic Archaea, which exhibit optimal activity between pH 6.8 and 7.2 (Gerardi, 2003). The inherent buffering capacity of the system allowed the reactor to operate continuously within this ideal range without any external pH correction, supporting both acidogenic and methanogenic microbial populations.

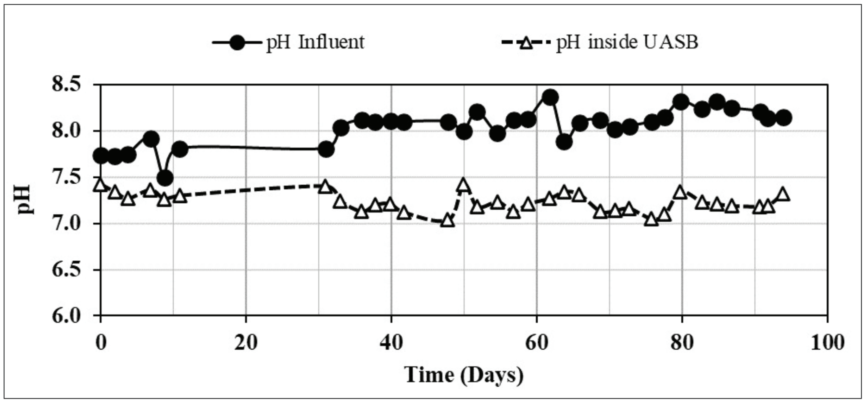

Figure 2: pH variation in influent (leachate) and inside the UASB

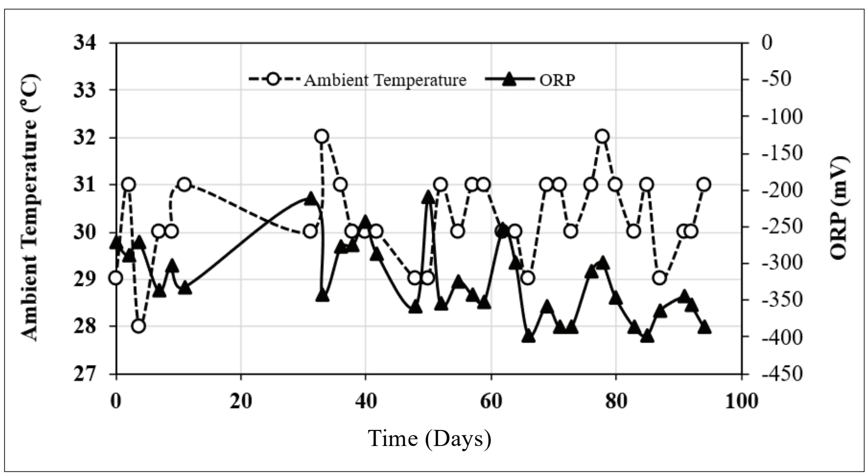

Figure 3: Ambient temperature and ORP variation inside the UASB reactor

Figure 3 presents the ambient temperature and ORP profiles recorded throughout the experiment. The reactor was operated under ambient conditions without thermal regulation, resulting in an internal temperature that fluctuated between 28 °C and 32 °C, with an average of 30 °C. Crucially, the ORP values remained consistently below -200 mV throughout the study, confirming that strictly anaerobic conditions were successfully established and maintained within the reactor.

BOD and COD removal efficiency

The reactor's performance was evaluated by systematically varying the OLR, controlled by adjusting the influent flow rate to alter the HRT. Throughout the study, the OLR was incrementally increased from 51.06 g-COD/L/d to 144.19 g-COD/L/d to identify the system's operational limits. The influent, sourced from a mature landfill, was characterized as a high-strength wastewater stream with average BOD_5 and COD concentrations of 7,918 mg/L and 23,625 mg/L, respectively. The resulting BOD_5/COD ratio was 0.34. This ratio can vary depending on the age of the landfill, and a value around 0.34 is typically observed in medium-aged leachates (5–10 years old), as reported by Bardi *et al.* (2017) and Ren *et al.* (2017).

As detailed in Figure 4, a clear performance peak was identified at an HRT of 6 h, corresponding to an OLR of 87.89 g-COD/L/d. Under these optimal conditions, the reactor achieved a maximum BOD_5 and COD removal efficiency of 69 ± 1% and 64 ± 1% respectively, and the most substantial absolute BOD_5 and COD reduction (a mean of BOD_5 is 3,942 mg/L and COD is 11,620 mg/L). This demonstrates the reactor's robust capacity for treating this challenging effluent under ambient tropical conditions. However, a critical operational threshold was observed: when the OLR was increased beyond this optimum, BOD_5 and COD removal efficiency decreased markedly. This trend aligns with previous findings where high loading rates lead to system instability, often termed shock loading (Satoh *et al*., 2017).

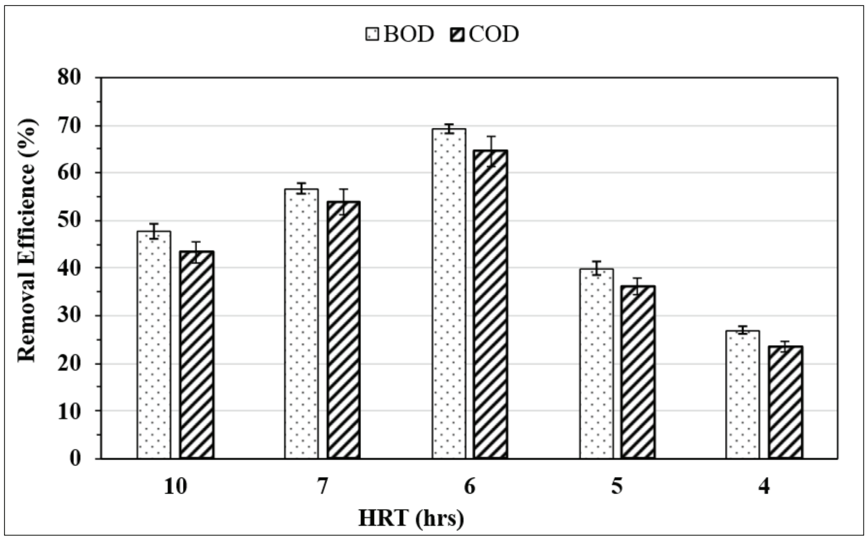

Figure 4: BOD5 and COD removal efficiencies variation with HRT

To evaluate the significance of these results, the reactor's performance was benchmarked against established design norms and similar research. Notably, the optimal OLR of 87.89 g-COD/L/d is substantially higher than the typical design range of 10–25 g-COD/L/d recommended by Metcalf and Eddy (2004) for high-strength anaerobic treatment. This exceptional loading capacity can be attributed to the well-acclimatized granular sludge, which demonstrated a remarkable ability to process the high substrate flux from the extremely concentrated leachate.

Furthermore, the 69% BOD_5 and 64% COD removal efficiency is highly competitive when compared to studies on similar stabilized or mature leachates in tropical regions. For example, Sponza and Ağdağ (2004) reported 62% COD removal from mature leachate, but at a much lower OLR of 12 g-COD/L/d. Similarly, Tatoulis *et al.* (2017) observed approximately 58% COD removal from stabilized leachate. The ability of our reactor to achieve a comparable efficiency at a significantly higher OLR highlights the robust metabolic activity of the microbial consortium established under Sri Lankan ambient conditions.

This comparative analysis confirms that while operating outside conventional OLR parameters, the UASB reactor provides effective treatment for highly concentrated, mature landfill leachate. The 64% COD removal achieved at ambient tropical temperatures, without supplementary heating, represents a viable and energy-efficient first-stage treatment, validating its potential for application in Sri Lanka and similar climatic regions. The sharp decline in performance beyond the 6-hour HRT, however, underscores the importance of maintaining the OLR below this critical threshold to prevent overloading and process failure, a finding corroborated by the biogas analysis.

Bio gas production

Biogas production and composition were systematically quantified for each HRT. As illustrated in Figure 5, the average biogas production rate varied with operational time, corroborating the COD removal profile. A maximum specific production rate of 23.35 ± 0.42 mL/h/L was achieved at the optimal HRT of 6 h, while the average rate across all conditions was 16.76 ± 0.85 mL/h/L. Decreasing the HRT below the 6 h optimum resulted in a corresponding decline in biogas generation.

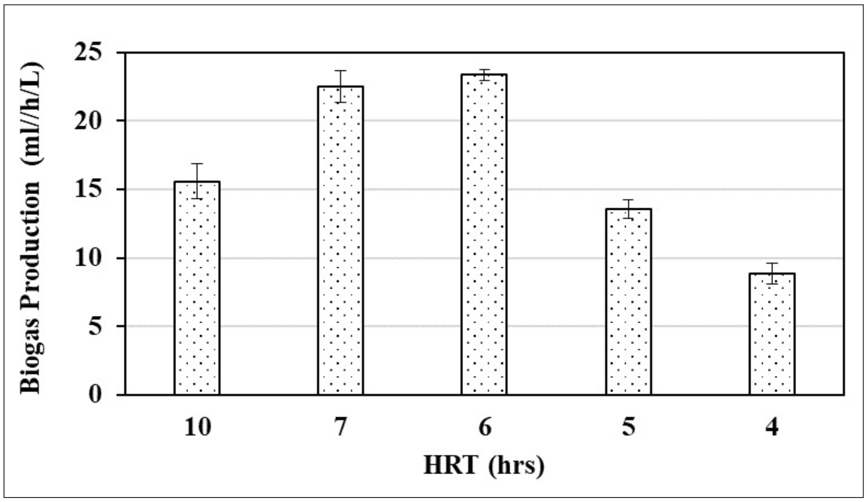

Figure 5: Bio Gas production rate variation with HRT

Table 1: Headspace biogas composition variation with HRT

HRT (hr.)	H_2 (ppm)	Gas concentration (%)		
		N_2	CH_4	CO_2
10	-	11.52 ± 2.77	82.99 ± 2.82	5.49 ± 0.65
7	-	10.31 ± 1.94	84.63 ± 1.26	5.06 ± 0.99
6	-	8.03 ± 1.24	86.11 ± 1.10	5.85 ± 0.89
5	137 ± 8	19.31 ± 0.42	68.32 ± 0.56	12.38 ± 0.39
4	252 ± 5	18.70 ± 0.84	73.16 ± 0.80	8.14 ± 0.14

The stability of the anaerobic process was further assessed by monitoring trace gas concentrations, as detailed in Table 1. The presence of H_2 in the headspace is a critical indicator of metabolic balance. As noted by Satoh *et al.* (2017), low H_2 partial pressure is essential for the syntrophic degradation of propionate and n-butyrate, and stress conditions such as short HRTs can lead to H_2 accumulation and subsequent process inhibition. In this study, operation at shorter HRTs (4 and 5 h) corresponded with an increase in H_2, N_2, and CO_2 concentrations, alongside a decrease in CH_4 percentage. The sudden increase in H_2 concentration to 252 ppm at the 4 h HRT suggests the system was approaching its metabolic equilibrium limit, indicating that further reductions in HRT would risk inducing an inhibitory state.

This observation is consistent with the findings of Pauss *et al.* (1990), who identified dissolved H_2 as a growth-limiting factor for acetogenic bacteria, which require its continuous removal by methanogens to maintain thermodynamic favorability. If the process is disrupted, competition for H_2 and acetate can intensify, particularly from sulphate-reducing bacteria, potentially leading to process failure. The low concentrations of N_2 detected (Table 1) are likely attributable to the release of dissolved nitrogen from the influent or the decomposition of nitrogenous compounds by non-methanogenic microorganisms.

Analysis of the biogas composition reveals that CH_4 was the predominant component across all tested HRTs. The CH_4 content varied with the HRT, reaching a maximum of 86.11 ± 1.10% at the 6 h HRT. This high methane yield indicates that the biogas produced under optimal conditions possesses a significant calorific value, reinforcing the selection of a 6 h HRT as the most effective operational parameter.

Removal of heavy metals

The role of heavy metals in anaerobic digestion is complex; while trace concentrations are essential for the activation of microbial enzymes and co-enzymes, higher concentrations can exert stimulatory, inhibitory, or toxic effects depending on the metal species and its bioavailability (Mudhoo & Kumar, 2013). Consequently, the reactor's capacity for heavy metal removal was evaluated specifically at the optimal HRT of 6 h.

Table 2: Heavy metal content variation with treatment

Heavy Metals	Influent (mg/L)	Initial granule (mg/L)	Effluent of UASB (mg/L)	Granule + Sludge (inside UASB (mg/L)
Pb	0.030 ± 0.002	0.011 ± 0.001	0.014 ± 0.002	0.676 ± 0.077
Hg	0.050 ± 0.002	0.000 ± 0.001	0.047 ± 0.002	0.144 ± 0.023
Cr	0.109 ± 0.002	0.032 ± 0.002	0.057 ± 0.003	2.116 ± 0.089
Cd	0.005 ± 0.001	0.002 ± 0.001	0.004 ± 0.001	0.041 ± 0.002
As	0.036 ± 0.002	0.002 ± 0.001	0.025 ± 0.002	0.467 ± 0.033
Fe	18.083 ± 0.072	0.732 ± 0.002	13.98 ± 0.06	169.80 ± 18.66

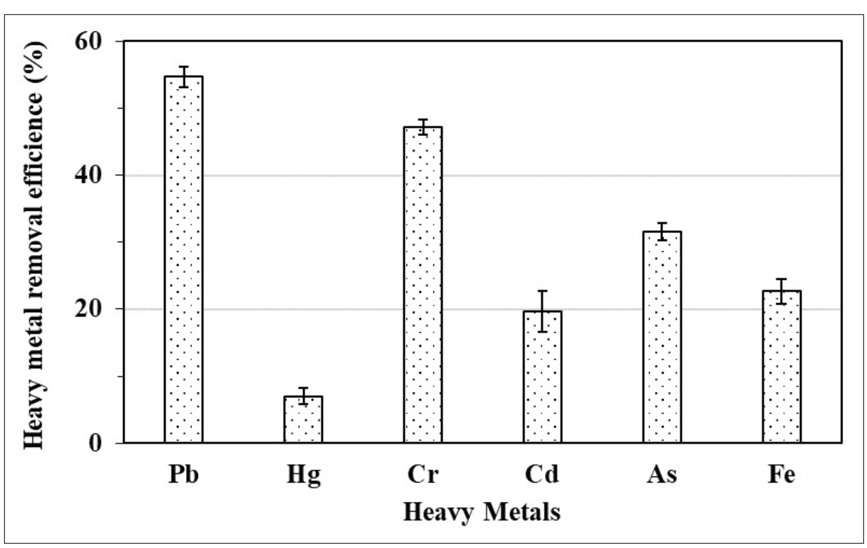

Figure 6: Heavy Metal removal efficiencies variation with HR

As detailed in Table 2, the influent leachate contained relatively low concentrations of most target metals, with the notable exception of Fe. However, low aqueous-phase concentrations in leachate do not necessarily imply an absence of metals in the waste. It is well-established that under the near-neutral pH conditions typical of anaerobic digesters, heavy metals tend to precipitate as insoluble sulphides, phosphates, and hydroxides (Berrueta & Castrillón, 1992; Kjeldsen *et al*., 2002). Evidence of this sequestration mechanism was confirmed by the post-treatment analysis of the reactor biomass, which showed a significant accumulation of heavy metals within the granular sludge (Table 2).

The overall removal efficiencies are presented in Figure 6. The system demonstrated the highest efficacy for Pb and Cr, with removal rates of 55 ± 1% and 47 ± 1%, respectively. In contrast, the UASB reactor was less effective for Cd, As, and Fe, while the removal of Hg was minimal at just 7 ± 1%.

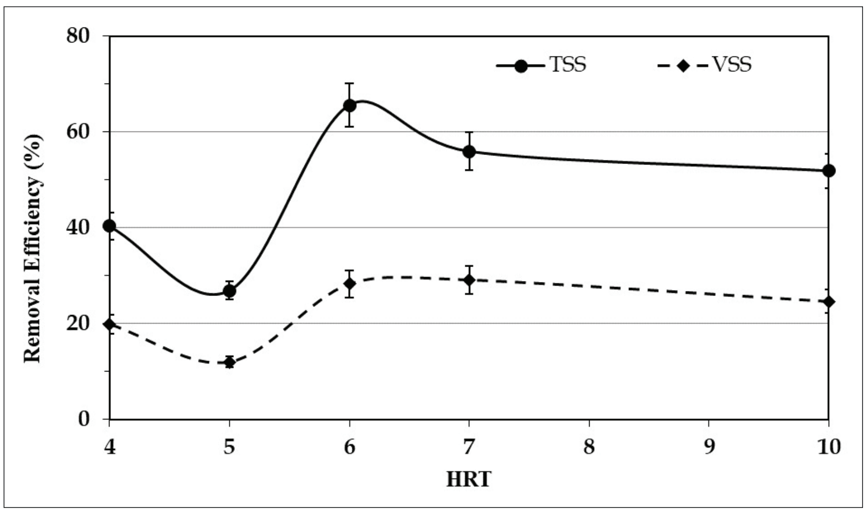

Figure 7: TSS and VSS removal efficiencies variation with HRT

Removal efficiencies of (TSS) and volatile suspended solids (VSS)

The influent leachate was characterized by high concentrations of TSS and VSS, with average values of 13,161 ± 1,864 mg/L and 4,495 ± 711 mg/L, respectively. The removal efficiencies for these solids across various HRTs are illustrated in Figure 7. A maximum TSS removal of 66% was achieved at the optimal HRT of 6 h, whereas the peak VSS removal of 29% was observed at an HRT of 7 h. Overall, the average removal efficiencies for TSS and VSS were 48% and 23%, respectively, indicating that the UASB reactor demonstrated modest efficacy for suspended solids removal from the liquid phase.

Table 3: TSS and VSS variation of granules initially and after the treatment

		TSS (mg/L)	VSS (mg/L)
Inoculated Granules		28832 ± 17	22737 ± 21
After treatment (In UASB reactor)	Granular	34654 ± 26	27381 ± 24
	Sludge	35602 ± 17	27667 ± 20

Conversely, a post-treatment analysis of the reactor biomass (Table 3) revealed a significant accumulation of both TSS and VSS within the granular sludge. This phenomenon can be attributed to a combination of the physical adsorption of suspended solids onto the granule surfaces and the concurrent generation of new biomass. The substantial increase in VSS is particularly significant; as reported by Risvi *et al.* (2015), an increase in VSS is a clear indicator of active biomass proliferation, given that over 90% of VSS typically comprises viable microbial cells, with the remainder being attributed to non-biodegradable volatile solids and cellular debris.

The evaluation of VSS/TSS ratio and OLR provided critical insights into the reactor's performance, revealing an average VSS/TSS ratio of 0.79 ± 0.05 that inversely correlated with increasing OLR, indicating robust microbial activity at optimal loading conditions (87.89 g-COD/L/d at 6 h HRT) but showing stress signs (ratio dropping to 0.73) at higher OLRs (144.19 g-COD/L/d). The system demonstrated remarkable resilience to common inhibitory factors, maintaining stable operation despite high ammonia levels (1,240 – 1,850 mg/L) through gradual biomass acclimatization and sufficient alkalinity buffering, while heavy metal effects were mitigated via sulphide precipitation and metal partitioning. Performance comparison showed the ambient-temperature UASB achieved competitive COD removal (64%) versus thermophilic systems, while avoiding energy-intensive heating. However, clear operational limits emerged at OLRs >90 g-COD/L/d, evidenced by 32% decreased methanogenic activity, VFA accumulation (1,450 mg/L propionate), and sludge washout. The VSS/TSS ratio proved to be a reliable bioindicator, with values >0.75 correlating with stable performance under these tropical ambient conditions, demonstrating the system's effectiveness within defined loading ranges while highlighting the need for OLR control to prevent overloading.

CONCLUSION

This study successfully demonstrated that a UASB reactor, operating under ambient tropical temperatures (28–32°C) without external heating, is a highly effective and robust technology for the first-stage treatment of high-strength, mature landfill leachate. The system achieved exceptional performance at an HRT of 6 h, corresponding to an OLR of 87.89 g-COD/L/d. At this peak, the reactor yielded a competitive 64% COD and 69% BOD_5 removal efficiency. This performance is particularly noteworthy as the operational OLR far exceeds the conventional design range of 10–25 g-COD/L/d, highlighting the remarkable capacity of the acclimatized granular sludge. This efficiency was directly corroborated by biogas analysis, which showed a maximum specific production rate of 23.35 mL/h/L and a peak methane content of 86.11%, underscoring the potential for valuable energy recovery. The reactor's stability was underpinned by its inherent buffering capacity, which maintained an ideal internal pH (7.0 – 7.5) for methanogenesis without chemical intervention, and its proven resilience to high ammonia concentrations. However, the research identified a clear operational boundary. Increasing the OLR beyond 90 g-COD/L/d (HRT < 6 h) led to a sharp decline in performance, marked by VFA accumulation, a 32% decrease in methanogenic activity, and a rise in H_2 gas concentration, a key indicator of metabolic stress and impending process failure. Furthermore, the VSS/TSS ratio proved to be a reliable bioindicator of system health, with a stable ratio above 0.75 correlating with optimal performance and a drop to 0.73 signaling overloading.

Regarding co-contaminant removal, the UASB reactor functions primarily as a sequestration system. It demonstrated moderate efficacy for heavy metals, with the highest removal observed for Pb (55 ± 1%) and Cr (47 ± 1%) through precipitation and accumulation within the sludge biomass. Conversely, removal was limited for Cd, As, and Fe, and minimal for Hg (7 ± 1%). Similarly, the system showed modest removal of suspended solids from the liquid phase.

In summary, the ambient-temperature UASB reactor is a viable solution for organic load reduction from mature landfill leachate in tropical regions. Its success hinges on maintaining the OLR below the critical threshold of 90 g-COD/L/d. While it effectively purifies the liquid effluent, the process concentrates heavy metals and solids into the sludge, necessitating proper management and disposal of this secondary waste stream.

REFERENCES

Baig, S., Coulomb, I., Courant, P., & Liechti, P. (1999). Treatment of landfill leachates: Lapeyrouse and Satrod case studies. *Ozone: Science & Engineering, 21*(1), 1–22. https://doi.org/10.1080/01919519908547239

Bardi, A., Yuan, Q., Siracusa, G., Chicca, I., Islam, M., Spennati, F., Tigini, V., Di Gregorio, S., Levin, D.B., Petroni, G. & Munz, G. (2017). Effect of cellulose as co-substrate on old landfill leachate treatment using white-rot fungi. *Journal of Bioresource Technology 241, 1067-1076.* https://doi.org/10.1016/j.biortech.2017.06.046

Berrueta, J., & Castrill, L. (1992). Anaerobic treatment of leachates in UASB reactors. *Journal of Chemical Technology & Biotechnology, 54*(1), 33–37. https://doi.org/10.1002/jctb.280540106

De Lemos Chernicharo, C. A. (2007). *Anaerobic Reactors* (Vol. 4). IWA Publishing.

Fonseka, H. A. M., Senewirathna, P. J., Bandara, W. M. K. R. T. W., & Ellawala, C. (2015). *Performance of a UASB reactor for leachate treatment under ambient temperature* [Unpublished undergraduate thesis]. University of Ruhuna.

Gerardi, M. H. (2003). *The microbiology of anaerobic digesters*. John Wiley & Sons. https://doi.org/10.1002/0471468967

Heyer, K.-U., & Stegmann, R. (1999). Leachate management. In T. H. Christensen, R. Cossu, & R. Stegmann (Eds.), *Landfilling of waste: Leachate* (pp. 1–23). E & FN Spon.

Ifeanyichukwu, M. J. (2008). *Water and environmental engineering* [Master's thesis, Lund University].

Karthikeyan, K., & Kandasamy, J. (2009). Upflow anaerobic sludge blanket (UASB) reactor in wastewater treatment. In S. Vigneswaran, M. Sundaravadivel, & S. Chaudhary (Eds.), *Water and wastewater treatment technologies* (Vol. II, pp. 180–198). Eolss Publishers.

Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long-term composition of MSW landfill leachate: A review. *Critical Reviews in Environmental Science and Technology, 32*(4), 297–336. https://doi.org/10.1080/10643380290813462

Kurniawan, T. A., Lo, W. H., & Chan, G. Y. (2006). Physico-chemical treatments of landfill leachate. *Journal of Hazardous Materials, 129*(1-3), 80-90.

Metcalf and Eddy (2004) *Wastewater engineering: Treatment and reuse*. (4th Ed.), McGraw-Hill.

Mudhoo, A., Kumar, S. (2013) Effects of heavy metals as stress factors on anaerobic digestion processes and biogas production from biomass. *International Journal of Environmental Science and Technology, 10*, 1383–1398. https://doi.org/10.1007/s13762-012-0167-y

Pauss, A., Andre, G., Perrier, M., & Guiot, S. R. (1990). Liquid-to-gas mass transfer in anaerobic processes: Inevitable transfer limitations of methane and hydrogen in the biomethanation process. *Applied and Environmental Microbiology, 56*(6), 1636–1644. https://doi.org/10.1128/AEM.56.6.1636-1644.1990

Ren, Y., Ferraz, F., Lashkarizadeh,, M., & Yuan Q. (2017). Comparing young landfill leachate treatment efficiency and process stability using aerobic granular sludge and suspended growth activated sludge. *Journal of Water Process Engineering 17*, 161-167. https://doi.org/10.1016/j.jwpe.2017.04.006.

Rizvi, H., Ahmad, N., Abbas, F., & Yasar, A. (2015). Start-up of UASB reactors treating municipal wastewater and effect of temperature / sludge age and hydraulic retention time (HRT) on its performance. *Arabian Journal of Chemistry, 10* (Suppl. 2), S2223–S2231. https://doi.org/10.1016/j.arabjc.2013.12.016

Satoh, H., Bandara, W. M. K. R. T. W., Sasakawa, M., & Okabe, S. (2017). Enhancement of organic matter degradation and methane gas production of anaerobic granular sludge by degasification of dissolved hydrogen gas. *Bioresource Technology, 245*, 1135–1141. https://doi.org/10.1016/j.biortech.2017.08.144

Sewwandi, B. G. N., Wijesekara, S. S. R. M. D. H. R., Rajapaksha, A., Mowjood, M. I. M., & Vithanage, M. (2011, November 29–30). *Risk of soil and water pollution by heavy metals in landfill leachate*. [Paper presentation]. International Conference on Agricultural Engineering Novelty, Clean and Sustainable, Nakhon Pathom, Thailand.

Shayan, M. N. M., Tushara Chaminda, G. G., Ellawala, K. C., & Gunawardena, W. B. (2020). Evaluation of water quality of community managed water supply schemes (CMWSS) in Galle District. In M. Kumar, F. Munoz-Arriola, H. Furumai, & T. Chaminda (Eds.), *Resilience, response, and risk in water systems* (pp. 139–150). Springer. https://doi.org/10.1007/978-981-15-4668-6_8

Sponza, D. T., & Ağdağ, O. N. (2004). Treatment of landfill leachate in a UASB reactor: Effect of organic loading rate and hydraulic retention time. *Environmental Technology, 25*(6), 707-718.

Tatoulis, T., Akratos, S., Tekerlekopoulou, A. G., Vayenas, D. V., & Pavlou, S. (2017). Performance of a full-scale UASB reactor treating landfill leachate: The case of the Al-Safa an Al-Faisaliah landfill in Jeddah, KSA. *Waste and Biomass Valorization, 8*(3), 883-893.

Wasala M. K. R. T. W. Bandara, Satoh, H., Sasakawa, M., Nakahara, Y., Takahashi, M., & Okabe, S. (2011). Removal of residual dissolved methane gas in an upflow anaerobic sludge blanket reactor treating low-strength wastewater at low temperature with degassing membrane. *Water Research, 45*(11), 3533–3540. https://doi.org/10.1016/j.watres.2011.04.008

Wasala M. K. R. T. W. BAndara, Shayan, M. N. M., Thennakoon, R. M. W. C., Kumudumali, P. A. A., & Satoh, H. (2024). Introduction of plug-flow anaerobic sludge blanket (PASB) reactor for wastewater treatment. *Desalination and Water Treatment*, 319, 130-139. https://doi.org/10.5004/dwt.2024.30335

Yuzer, B., Akgul, D., & Mertoglu, B. (2012). Effect of high ammonia concentration on UASB reactor treating sanitary landfill leachate. *Fen Bilimleri Dergisi (FABAD), 24*(2), 59–67.