From trash to treasure: civil construction wastes as alternative filling materials for constructed wetlands

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Highlights:

- Civil construction waste can be used as filling material in CW.
- CW-RC had the lowest removal efficiencies for TN (48%) and TP (64%) than the other systems.
- CW-AC and CW-CAC had similar removal efficiencies of 72% for TN and 77% for TAN.

Keywords: Red ceramic; Aerated concrete; Chemically activated aerated concrete.

INTRODUCTION

Constructed wetlands (CWs) are a low-cost, effective, and sustainable approach to treating wastewater, in which simultaneous processes (adsorption, complexation, plant uptake, nitrification, denitrification, and ammonia volatilization) are responsible for removing organic matter and nutrients, among other pollutants. Raw materials from civil construction (RMC) are widely generated in civil construction due to failures in chain processing management. These wastes have been explored as CW-filling materials because of their physicochemical composition and textural and morphological properties that provide great capacity for adsorption. Therefore, this study investigates red ceramic, aerated concrete, and chemically activated aerated concrete as filtering materials to remove COD and nutrients in VFCW.

METHODOLOGY

Three subsurface vertical-flow constructed wetlands (VFCW), in microcosm scale with a surface area of 0.2 m², were installed at the Federal University of Technology - Paraná (UTFPR) in Curitiba, Paraná State. The systems were planted with *Eichornia crassipes* macrophytes (density of 25 plants m^{-2}) onto fragments of red ceramic (CW-RC), autoclaved aerated concrete (CW-AC), and composite formed from autoclaved aerated concrete chemically activated with white cement (CW-CAC). The systems were filled with a 0.20 m layer of each substrate and maintained a 0.05 m layer as a saturated bottom. VFCWs were fed manually with synthetic wastewater, according to [1], in cycles of 48-48-72 h, resulting in applied loading rates of 0.68 ± 0.06 g m^{-2} d^{-1} of COD, 0.3 ± 0.1 g m^{-2} d^{-1} of TN, 0.171 ± 0.020 g m^{-2} d^{-1} of TAN, 0.036 ± 0.013 g m^{-2} d^{-1} of nitrite, 0.4 ± 0.1 g m^{-2} d^{-1} of nitrate, and 0.06 ± 0.01 g m^{-2} d^{-1} of TP, totalizing 364 days of operation. pH, dissolved oxygen (DO), total alkalinity (TA), ORP, turbidity, chemical oxygen demand (COD), total Kjeldhal nitrogen (TKN), total ammonia nitrogen (TAN), nitrite, nitrate, and total phosphorous (TP) were determined in influent and effluent samples of the VFCWs [2,3]. Statistical analyses were performed by using Shapiro-Wilk test for normality verification ($p \leq 0.05$) and Kruskal-Wallis non-parametric test (p-value ≤ 0.05) with the free software BioStat.

RESULTS AND CONCLUSIONS

Monitoring of pH, TA, DO, ORP, and turbidity are presented in Table 1. In this study, pH ranged from 6.5 to 7.9 in the influent samples, and no variation was noted on the effluent samples of CW-RC; however, CW-AC and CW-CAC exhibited an increase, achieving maximum values of 8.6 and 8.8, respectively. The increase in pH in these systems may be related to the release of hydroxyl radicals and carbonates from the materials [4,5]. In addition, the determined pH values indicate that the CWs studied tend to volatilize ammonia. According to the International Water Association [6], the pH range between 7.5 and 8.6 is favorable to nitrification.

Total alkalinity varied from 49.5 to 70.1 mgCaCO L^{-1} in the influent and resulted in average of 49.5, 73.7 and 86.9 $mgCaCO_3$ L^{-1} in the effluent of CW-RC, CW-AC, and CW-CAC, respectively. According to the statistical analysis, there is no significant difference between the influent and effluent samples (0.1514 ≤ *p-value* ≤ 0.1806). However, a significant difference (*p-value* < 0.05) was observed between CW-RC and other effluents. Total alkalinity directly influences the ammonia nitrification process. The reaction balance proposes that 7.1 g of $CaCO_3$ are required to nitrify 1 g of ammonia [7].

Dissolved oxygen concentrations indicated that the systems were operated under anoxic conditions (< 2 mg L^{-1}), according to Metcalf and Eddy [8]. ORP varied from -226 to +62 mV in the effluent samples, suggesting both anaerobic and anoxic conditions. The average turbidity in the influent was 4.77 ± 0.83 NTU, and greater variations were observed in the effluent from 5.76 to 10.1 NTU in CW-RC; 2.34 to 9.63 NTU in CW-AC; and 3.67 to 8.64 NTU in CW-CAC. The turbidity of the influent showed a significant difference compared to the turbidity of the effluent samples (*p-value* = 0.0002), suggesting that civil construction materials can release solids that increase the turbidity of the treated synthetic sewage.

Table 1: Physical and chemical parameters of synthetic wastewater before and after treatment.

Parameters	**Influent**		**CW-RC**		**CW-AC**		**CW-CAC**	
	Min	Max	Min	Max	Min	Max	Min	Max
pH	6.5	7.9	6.7	9.3	7.6	9.3	8.3	9.1
Turbidity (NTU)	2.98	5.54	5.76	10.10	2.11	4.48	1.96	6.10
Dissolved oxygen (mg L^{-1})	0.77	1.77	0.24	0.55	0.36	0.67	0.36	0.68
ORP (mV)	-114	113	-209.0	143.0	-226.0	44.0	-206.0	62.0
TA ($mgCaCO_3$ L^{-1})	49.5	70.1	41.1	68.2	46.6	89.7	72.9	108.4

CW-RC, CW-AC, and CW-CAC achieved COD removal efficiencies of 72, 73, and 77%, respectively (Figure 1). COD range in influent indicates a weak sewage (COD < 250 mg L^{-1}) [8]. There is a significant difference between the influent and effluent samples ($0.0001 \leq p \leq 0.0008$). Comparing effluents, there is no significant difference for COD (*p-value* ≥ 0.4163).

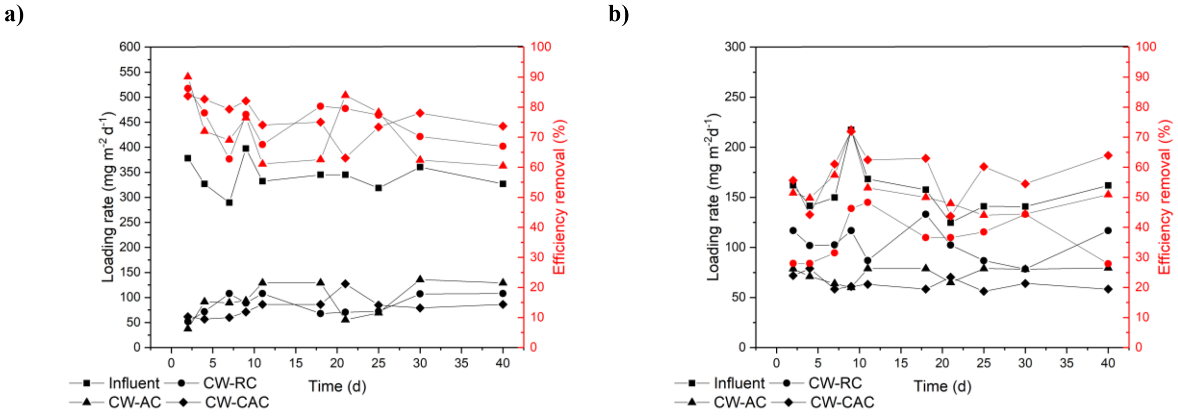
TN removal efficiencies of 48% (CW-RC), 72% CW-AC, and 72% (CW-CAC) were found. TN in the influent was different from the systems (*p-value* ≤ 0.0456). Among effluents, WC-AC and WC-CAC had significant difference (*p-value* < 0.05) compared to WC-RC.

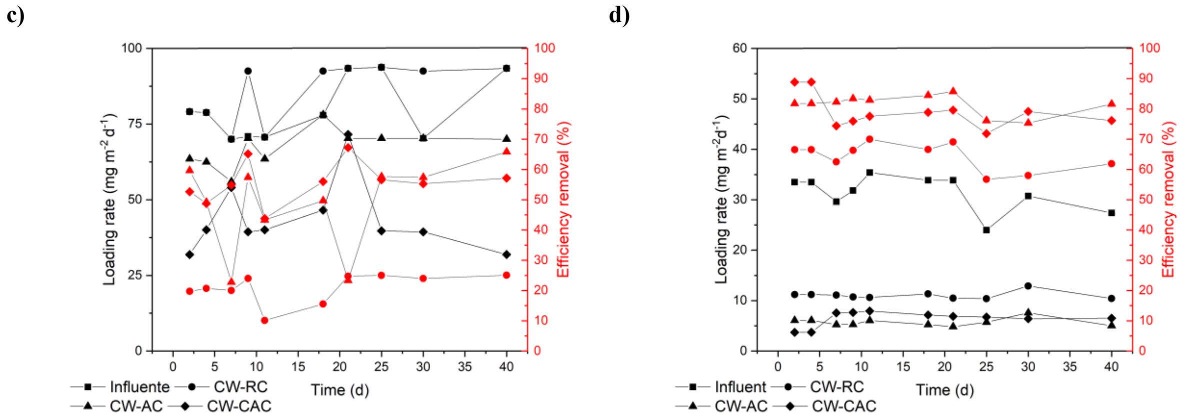
Unfortunately, CW-RC did not show TAN removal. However, influent was different ($p \leq 0.0001$) compared to the CW-AC and CW-CAC, resulting in removal efficiencies of 67%. Comparing the systems, CW-AC and CW-CAC systems were statistically equal (*p-value* = 0.1967) for NTA.

Nitrite concentrations ranged from 0.006 to 0.014 mg L^{-1} in the influent, and from 0.004 to 0.010 mg L^{-1} in CW-RC, 0.001 to 0.010 mg L^{-1} in CW-AC, and 0.001 to 0.007 in CW-CAC. Nitrite in effluent was statistically lower than influent (0.0003 ≤ *p-value* ≤ 0.0151). nitrate ranged from 0.3 to 0.7 mg L^{-1} in the influent. A significant difference was observed between the influent and the effluents of the system (*p-value* ≤ 0.0177), resulting in removal efficiencies of 27% to 41%. The effluents did not present significant differences between them (*p-value* ≥ 0.1124).

Total phosphorus ranged from 9.6 to 14.2 mg L^{-1} in the influent. This concentration was statistically different (*p-value* ≤ 0.05) from the system outlet concentrations. In the effluents, removal percentages of 82% (WC-CA), 79% (WC-CQA), 64% (WC-CV) were achieved. The phosphorus concentration in the CW-RC system was different from CW-AC and CW-CAC (*p-value* ≤ 0.0164) systems. However, CW-AC and CW-CAC systems were statistically equal (*p-value* = 0.3486). Overall, CW-RC presented lower nutrient removal efficiency, and CW-AC and CW-CAC showed similar results of efficiency removals. However, CW-AC does not require chemical activation, reducing the costs and preparation time of the filtering material. These findings provide insights into optimizing constructed wetland systems, emphasizing the potential benefits of using specific substrates for enhanced wastewater treatment.

Figure 1: Monitoring of organic matter and nutrients removal.





Note: a) Chemical demand of oxygen (COD); b) Total nitrogen; c) Ammonium nitrogen; d) Total phosphorous.

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