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Performance evaluation of enriched lab-scale oxidation ponds for treating municipal wastewater

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ABSTRACT

This work aims to examine the feasibility of improving the performance of traditional oxidation ponds by adding acclimatized activated sludge, which has been proposed as an efficient and enriching approach for rapidly increasing the concentration of active biomass in these ponds. On this basis, the treatment system was evaluated by operating two cycles on a lab-scale setup; each experimental cycle was composed of three ponds positioned serially and independent of one another for a comparative study of pollutant removals and determination of which was best, the enriched ponds or non-enriched ponds. The experiment results highlighted that the enrichment leads to high rates of degradation when compared to un-enriched stabilization ponds and obtained better average elimination efficiencies of chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), total nitrogen (TN), and total phosphorus (TP) at 89.92%, 91.45%, 49.85%, and 53.63%, respectively. Furthermore, the average removal efficiency of coliforms was 99.98%. The results show that improved waste stabilization ponds offer a practical, independent, and sustainable sewage treatment option for irrigation water supply.

Keywords: enriched oxidation ponds, improvement, performance evaluation, treating wastewater.

INTRODUCTION

Oxidation ponds, or named waste stabilization ponds, currently correspond to municipal and industrial effluent treatment systems, and there is evidence of its discovery in San Antonio, Texas, since 1901. Their primary unique feature is their capacity to provide efficient outflow treatment conditions depending on the microorganism's presence without requiring expensive building prices (Awad et al., 2024), making the stabilization ponds beneficial economically. They enable wastewater treatability with low energy, construction, and maintenance costs, making them easier to adopt in developing and developed nations. It is worth mentioning that these technologies have been routinely utilized in Germany and France for numerous years (Mara et al., 2018). Meanwhile, ponds account for approximately 50% of sewage treatment plants in the USA (Long et al., 2017). With Canada's cold climate, waste stabilization ponds (WSPs) remain the most popular sewage treatment approach (Colin et al., 2015). Still, these technologies are highly used in hot and developed nations because of their availability of area, easy operation, and the need for little or no equipment(Von Sperling et al., 2005).

Despite their advantages, their application is also associated with some essential disadvantages. For example, this technology typically has a relatively low active biomass concentration (Polprasert et al., 1995; Barjenbruch et al., 2005), leading to a low reaction rate (Abdel-Shafy & Salem, 2007). Therefore, a large area is needed for their implementation to ensure sufficient effluent quality(Pearson & Mara, 1987). Additionally, stabilization ponds only partially treat wastewater, where they can remove organic matter and pathogenic microorganisms efficiently, but their ability to remove nutrients (nitrogen and phosphorus) is limited to a lesser extent (Silva et al., 2010). Therefore, their effluent cannot, strictly speaking, be discharged into surface waters as is currently done since the availability of essential nutrients can lead to surface water toxicity and eutrophication, characterized by excessive plant growth and algae blooms, with profound implications for water quality (Murdoch et al., 2000; Driscoll et al., 2003; Preston et al., 2011). Moreover, the presence of constituent ammonium (NH_4^+-N) and ammonia (NH_3) can have various negative impacts on water bodies, including water color change, reduced dissolved oxygen levels due to nitrifiers bacteria, and direct toxicity to aquatic life (Wright et al., 1986; Playle & Wood, 1989; Bitton, 1999).

In view of this, it is clear that the optimization of the operation of an oxidation pond system must be taken into account because when well designed and operated, it can produce effluents with excellent sanitary conditions and satisfactory elimination of organic material, reducing the effect of the organic load on the receiving aquatic bodies or it can reuse for irrigation. In particular, the idea of treating and reusing wastewater is becoming more and more popular in all parts of the globe in both industrialized and developing nations, especially in regions that experience water resource shortages (Hobus & Hegemann, 2001; Abdel-Shafy et al., 2003; Mara, 2007; Al Baz et al., 2008). In recent years, many studies focused on modifying conventional stabilization ponds to improve treatment effectiveness (Rinhofer & Smith, 2010; Babu et al., 2011; Faleschini et al., 2013; Moumouni et al., 2015; Ouedraogo et al., 2016; Khan et al., 2017; Dias et al., 2017; Bassuney & Tawfik, 2017; Sasani et al., 2017). Among these modifications is a proposal for rapidly increasing biomass concentration, which is predicated on an enriching approach (Shin et al., 1987;; Polprasert et al., 1994; Polprasert et al., 1995; Zhao & Wang, 1996; Muttamara et al.,1997; Rakkoed et al., 1999). A prior study by Avelar et al. demonstrated that enrichment with activated sludge from the municipal sewage facility could significantly raise the active biomass content in laboratory pond experiments. They observed that these enriched ponds removed organic matter twice as fast as conventional lagoons, and the biomass produced by the enrichment process was the primary cause of pollutants' elimination (Avelar et al., 2001; Avelar et al., 2003; Ramos et al., 2005).

Therefore, the current work examines the effectiveness of improving traditional ponds for treating municipal wastewater, especially increasing their efficiency in removing nitrogen and phosphorus. This improvement was achieved by enriching it with activated sludge without changing the dimensions of the traditional pond treatment system. Further, the impact of this process on treating before and after upgrading was also investigated through the operation of two cycles on a lab-scale setup; each experimental cycle was composed of three ponds positioned in a series and independent of one another for the study of enriching stabilization ponds by inoculating them with activated sludge and comparing them to unenriched lagoons. The evaluation of the treated wastewater for irrigation reuse is also carried out.

MATERIALS AND METHODS

Experimental unit description

The experimental unit was constructed using three identical laboratory-scale stabilization ponds to treat 12.5 L/day municipal wastewater. Each cell has a working dimension of length of 100 cm, 25 cm wide, and 35 cm deep, with hydraulic residence times equal to seven days. They were installed at the municipal sewage treatment plant in Al Rumaitha town, north of Al Muthanna government, Iraq, in an external area subject to climate change. These ponds were arranged in series to treat municipal wastewater. Each pond was made of stainless steel. All edges, vertices, and welding points were sealed with silicone to prevent possible leaks. Figure 1 illustrates a diagram representing three laboratory ponds, whereas the photograph of the laboratory-scale pond system set up on site is shown in Figure 2. The input flow sewage for the experimental unit was continuously pumped after the Al-Rumaitha treating facility's preliminary on-site treating phase, which contained roughing, sieving, sandblasting, and defatting steps into the 500-litre cylinder primary sedimentation tank installed above the laboratory unit, where the sedimentation of suspended solids occurred. This tank allows the sewage to flow by gravity to the first of the ponds without a pump through a 25-mm PVC hose pipe; after that, the ponds were installed and connected at equal distances along the series. A 25 mm PVC hose was used to connect the outlet inlet of the ponds in series. The ground level of the three lagoons is designed to allow flow by gravity.

Inoculum and operation procedure

In this operation research, laboratory units were designed and constructed to investigate

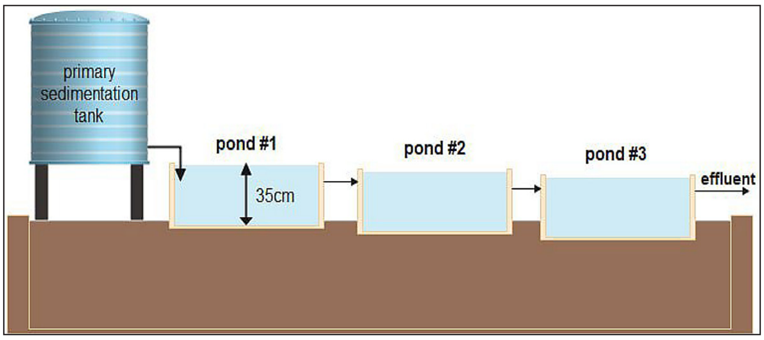

Figure 1. Diagram of the three ponds treatment system

Figure 2. Photograph of laboratory-scale pond system setup on site

the impact of enriched with activated sludge on multiple ponds operating in series compared with conventional ponds as a potentially suitable technique to improve pond efficiency of organic matter removal, especially nutrient removal from municipal wastewater. Therefore, the treatment system was evaluated through two operational cycles on a lab-scale setup; each experimental cycle was initially composed of three ponds positioned in a series and independent of one another for a comparative study of pollutant removals to determine which was best, the enriched ponds or conventional ponds.

In the first cycle, external seeding was not used, so the three ponds were not enriched with activated sludge but filled and operated with real municipal wastewater. The first four weeks of this cycle experiment were operated as the startup phase as follows: For one week, the pond systems were operated in batch mode to evaluate the microbial community and algae, and for three weeks, they were operated continuously to prepare for the continuous operation. In contrast, the system underwent initial seeding in the second operational cycle, during which the three ponds were enriched, each with approximately 21.9 L (25% of the working volume) of previously prepared activated sludge from the secondary sedimentation tank of the sewage treatment facility's municipality of Rumaitha. The inoculation phase began with the seed preparation phase and lasted three days. It started by gathering the seeds, extracting any inorganic material via a sieve with small holes, and then allowing them to aerate for two days at room temperature. The aeration was stopped on the fourth day, and the seeding

– sludge was introduced to the system according to the specified ratio. Then, the ponds' work volume was completed with real municipal sewage. An enriched phase lasted 4 weeks; after this period, the oxidation pond was ready for launch. The first and second cycles were operated identically except for the enrichment procedure. After that, the continuous operation mode began; the ponds were continuously fed by gravity from the sedimentation tank throughout the experiment, with a maintaining hydraulic residence time of 7 days. Every cycle, the pond receives the same amount of water (12.5 L/day). The feeding was located 5 cm above the base of the first cell. This pond experiment was initiated in the early summer to capitalize on the increased activity rates of bacteria associated with high temperatures. According to documentation in the literature, the activity of bacteria is higher in the summer than in winter (Mama et al., 2011), and the more effective the treatment, the warmer the pond's contents. This study experiment lasted 20 weeks, with an average duration of 10 weeks for each cycle.

As mentioned previously, the initial four weeks were dedicated to the startup phase, during which the pond situation for each cycle was continuously monitored regarding the dissolved oxygen (DO) content, pH, and sewage color. The photosynthesis algal development was proven when the effluent turned a vivid green tone, indicating the presence of healthy algal growth, as shown by the increase in DO content consistently above 2 mg/L and high pH. The breakdown of organic matter, a typical outcome of the symbiotic relationship between bacteria and algae, is fascinating. Bacteria utilize algae's oxygen to metabolize organic substances in an aerobic environment, releasing carbon dioxide and diluted nutrients (nitrates, phosphates). This process is efficient and mutually beneficial, as algae utilize these resources during their growth, enhancing both activities (Von Sperling, M., 2005; Awad et al., 2023). In the oxidation pond system, algae also play an essential role in eliminating all forms of nitrogen and phosphorus from raw sewage through assimilating these nutrients as they grow. After several thorough trials, it was determined that a better option depended on the best elimination – especially removing COD, NH_4^+-N, TN, and TP. These findings are crucial as they provide a clear understanding of the importance of enriching with activated sludge, which enhances the overall performance of the three-cell pond system.

Properties of ponds system raw sewage

Raw sewage must be characterized to comprehend the suggested treatment strategy and evaluate the effectiveness of the pond technique and its resilience to changes in input flow composition during experiments. Therefore, actual municipal sewage, with different concentrations of contaminants, was used as the influent flow to guarantee the accuracy of the results. Indeed, real sewage is recommended for utilization because of its varied microbial community and easier biodegradability than synthetic wastewater. Therefore, regular sewage characterizations were carried out during the biological system's whole operating duration, acknowledging that the sewage's composition might change over time. Among them, the chemical analyses COD, NH_4^+-N, TN, and TP, which are important metrics for evaluating effluent quality, are tabulated in Table 1 (adapted from an earlier study by Awad et al., 2023), which shows the features of major pollutants in municipal wastewater.

Sampling and laboratory analytical

Throughout the experiment, samples were collected from influent raw sewage and the outflow from the final pond to evaluate the efficacy of the experimental unit on a lab scale. Samples for this study are analyzed for parameters COD, NH_4^+-N, TN, and TP following the procedures outlined in Standard Methods (APHA, 2005). These tests were conducted in the laboratories of the same sewage facility. At the same sample time, an OHAUS portable meter (ST300D model) tested the dissolved oxygen while a thermometer recorded the liquid temperature. In contrast, the WTW portable pH meter (model 3110) was used to test the pH at the work site.

RESULTS AND DISCUSSION

The pond system's performance in chemical parameter elimination of COD, NH_4^+-N, TN, and

Table 1. Characteristics of raw sewage input flow

Parameter	Range
COD	175–500 mg/L
NH_4^+-N	25–50 mg/L
TN	35–55 mg/L
TP	4–8 mg/L

TP under two various operating cyclic modes has been summarized in Table 2, whereas Tables 3 and 4 present the results of these analyses, which are represented as the average, standard deviation, and efficiency attained for each operation cycle. It should be mentioned that the work was performed in ambient air temperatures ranging from 25–45 °C. The mean temperature of the ponds was maintained at 21±2 °C. Physical parameters such as DO and pH are also monitored daily as routine analyses. Daily monitoring results of DO content, conducted for the different cycle modes, showed that DO fluctuation is natural compared to what is usually anticipated in the cyclical rise and fall during the day and night for all three cells. Increasing DO values progressively from the first cell to the third cell might be due to low organic matter pollution. In contrast, the incoming flow and outflow pH ranged between 7.6–8.2 and 7.3–9.0, respectively, suitable for precipitating some metals in sewage. Although the pH varied, the outflow for different cyclic operation modes met the pH values of 5.5–9.5 for sewage discharge into aquatic surfaces, which was specified according to the DWA guideline (DWA, 2010). Regarding pH variation, the high DO value is consistently accompanied by a simultaneous high pH value, which is accompanied by increased algal activities during daytime hours. The rising pH level is due to carbon dioxide (CO_2) consumed during the algae photosynthesis process, leading to nitrogen removal by producing free ammonia. This form of ammonia is subject to volatilization, resulting in release into the ambient air. Also, removing phosphate by precipitation will occur at high pH levels above eight and can remove the most phosphorus (Awad et al., 2023).

Removal of COD at various operating cycle modes

COD indicates the quantity of energy and carbon inside the reactors available to the microbial community. It represents the amount of oxygen necessary to degrade organic compounds present in samples that may or may not be biodegradable (Hussein, 2023). Higher COD values indicate a larger amount of organic material or pollutants within the water, which can contribute to decreased dissolved oxygen levels and negatively impact aquatic ecosystems (Hussein, 2023); therefore, for this study, Figure 3 and Table 2 show the input, output COD, and removal efficiency concentrations changing with different operating cycles. In contrast, Tables 3 and 4 display the system's mean COD elimination efficiency. Data show a clear difference between the enriched and non-enriched ponds and their influence on removing COD from the system. Notably, the most significant reduction in COD was observed in operating cycle # 2, when these ponds were inoculated with activated sludge, reaching an impressive value of 89.92% (SD = 0.74). This was accompanied by an average effluent concentration of 39.17 mg/L (SD = 9.66), indicating a superior increase of microorganisms in the liquid medium and more efficient oxidation of organic matter. In contrast, the mean COD elimination at the first cycle mode

Table 2. Outlines the findings of pond system performance under various operating cyclic modes

Operating cycle modes	COD			NH_4^+-N			TN			TP		
	Inflow mg/L	Outflow mg/L	R.%	Inflow mg/L	Outflow mg/L	R.%	Inflow mg/L	Outflow mg/L	R.%	Inflow mg/L	Outflow mg/L	R.%
1st	315	86	72.70	30.8	8.39	72.76	48.1	30.81	35.95	7.5	4.41	41.20
1st	500	141	71.80	42.2	9.33	77.89	44.1	26.52	39.86	5.99	3.67	38.73
1st	357	98	72.55	33.64	9.01	73.22	41.89	27.41	34.57	4.45	2.8	37.08
1st	311	88	71.70	29.5	6.8	76.95	50.92	30.61	39.89	6.04	3.86	36.09
1st	408	121	70.34	36.76	7.56	79.43	47.23	29.14	38.30	5.87	3.46	41.06
1st	331	98	70.39	30.19	7.44	75.36	43.2	27.92	35.37	6.24	4.03	35.42
2nd	484	52	89.26	40.08	3.89	90.29	58.34	28.21	51.65	6.06	2.98	50.83
2nd	367	35	90.46	30.3	3.21	89.41	46.87	24.14	48.50	6.47	3	53.63
2nd	301	31	89.70	46.31	3.78	91.84	52.78	25.68	51.35	5.94	2.81	52.69
2nd	351	34	90.31	27.9	2.11	92.44	42.97	21.14	50.80	7	3.23	53.86
2nd	461	51	88.94	30.7	2.33	92.41	49.7	26.22	47.24	5.47	2.46	55.03
2nd	349	32	90.83	37.3	2.87	92.31	54.18	27.31	49.59	5.76	2.55	55.73

Table 3. Mean pond system performance under various operating cyclic modes

Operating cycle modes	COD			NH_4^+-N			TN			TP		
	Av. Inflow mg/L	Av. outflow mg/L	Av. R%	Av. Inflow mg/L	Av. outflow mg/L	Av. R%	Av. Inflow mg/L	Av. outflow mg/L	Av. R%	Av. Inflow mg/L	Av. outflow mg/L	Av. R%
1st	370.33	105.33	71.58	33.85	8.09	75.93	45.91	28.74	37.32	6.02	3.71	38.26
2nd	385.50	39.17	89.92	35.43	3.03	91.45	50.81	25.45	49.85	6.12	2.84	53.63

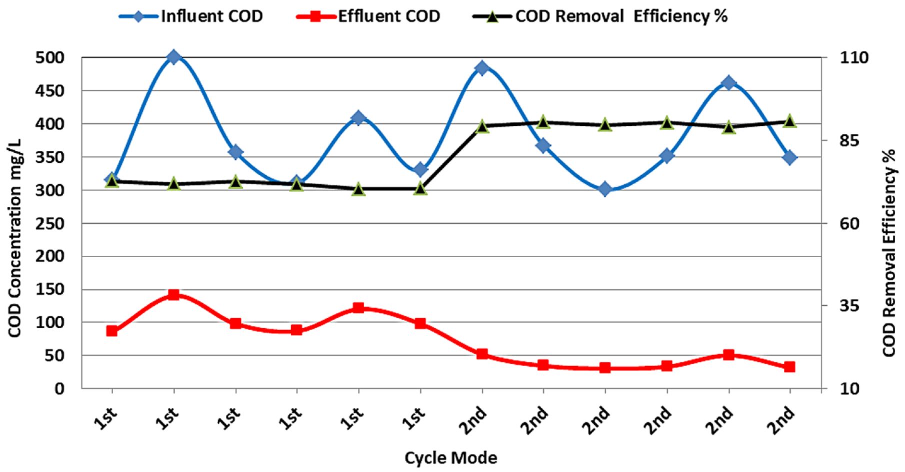

Figure 3. Input, output, and the elimination efficiency for COD under various operating cycle modes

Table 4. The standard deviation of pond system performance under various operating cyclic modes

Operating cycle modes	COD			NH_4^+-N			TN			TP		
	Inflow S.D. mg/L	Outflow S.D. mg/L	R. S.D. %	Inflow S.D. mg/L	Outflow S.D. mg/L	R. S.D. %	Inflow S.D. mg/L	Outflow S.D. mg/L	R. S.D. %	Inflow S.D. mg/L	Outflow S.D. mg/L	R. S.D. %
1st	72.86	21.44	1.02	4.90	0.98	2.64	3.42	1.75	2.34	0.97	0.55	2.48
2nd	71.28	9.66	0.74	7.06	0.73	1.29	5.48	2.53	1.74	0.54	0.29	1.74

was nearly 71.58% (SD = 1.02), and the outflow concentration was approximately (105.33 mg/L and SD = 21.44). Overall, the pond system demonstrated commendable efficiency in removing COD, with 89.92% in enriched ponds; this underscores the system's capability to remove organic matter when improved effectively.

Removal of ammonium (NH_4^+-N) at various operating cycle modes

Nitrogen can be present in municipal or industrial wastewater and water bodies in different forms, either as organic nitrogen(coming from organic protein compounds and amino acids and human urea) (Jordao & Pessoa, 2005) or inorganic such as ammonia (NH_3-N), ammonium (NH_4^+-N), nitrite (NO_2-N) and nitrate (NO_3-N) (Gray, 1989; Crites & Tchobanoglous, 1998; Tchobanoglous et al., 2003). Since a small amount of these compounds was adequate to cause eutrophication phenome, nitrogen elimination has become crucial in sewage treatment.

Thus, this study section used the ammonium and total nitrogen (TN) tests in the next section, which measure all the forms of nitrogen in the sample. Therefore, Figure 4 and Table 2 present ammonium concentrations in the inlet, output, and total efficiency for two-cycle modes. Our work's findings are significant, showing a general drop in the system's effluent concentration during these two cycles. Therefore, the average final concentrations to determine the better performance between conventional ponds and enhanced ponds are 8.09 mg/L (SD = 0.98) for cycle mode#1 and 3.03 mg/L (SD = 0.73) for cycle mode #2. When

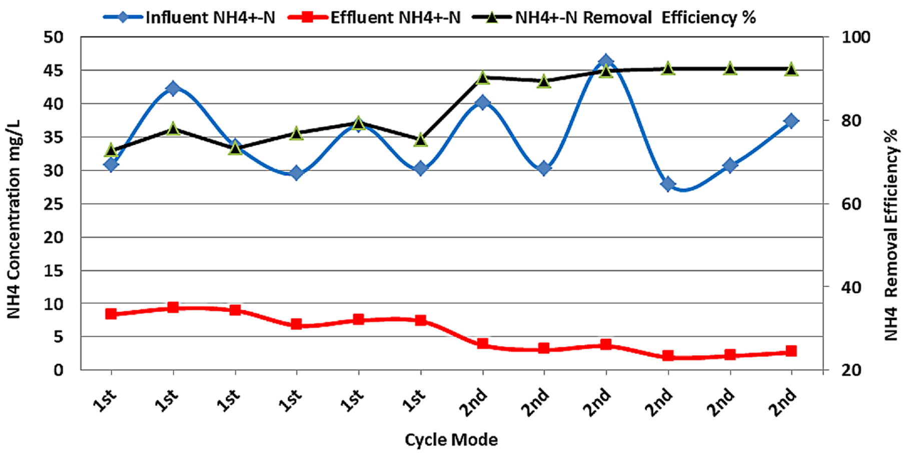

Figure 4. Input, output, and the elimination efficiency for ammonium under various operating cycle modes

comparing the NH_4^+-N removal between these cyclic modes, #1 and 2, it was noted that the removal percentages in the first operation mode were lower by 75.93% (SD = 2.64). However, the most significant finding was the removal of NH4+-N in the second operation cycle, which was 91.45% (SD = 1.29) when inoculated into the pond system, demonstrating this improvement's effectiveness and reliability.

Removal of total nitrogen (TN) at various operating cycle modes

This study measured the total nitrogen input, output flow, and removal efficiency concentration under two different operating cycles for enriched ponds and traditional stabilization ponds over the operating time. The crucial results, presented in Figure 5 and Table 2, highlight the effectiveness of such cycles of two operation modes in removing nitrogen.

The above table shows that the system's raw wastewater has a mean total nitrogen concentration of 48.36 mg/L (with SD = 5.05), which is approximately within the typical limits for municipal sewage, from 35 to 60 mg/L, mentioned by the researcher von Sperling (2005); however, they are still below the means documented in works by Oliveira (2006), equal to 66 mg/L, and works by Destro et al. (2007), equal to 80 mg/L. According to Jordão and Pessôa's 2011 classification, TN concentration for this work is located between "medium wastewater" (having a value equal to forty mg/L) and "strong wastewater" (having a value equal to eighty-five mg/L); it is close to the first. Also, results show that the average final concentrations for each operating cycle mode are 28.74 mg/L (SD = 1.75) for cycle #1 and 25.45 mg/L (SD = 2.53) for cycle #2. The results clearly show the difference in the removal percentage for the operating cycle modes 1st and 2nd: 37.32% (SD = 2.34) and 49.85% (SD = 1.74), respectively.

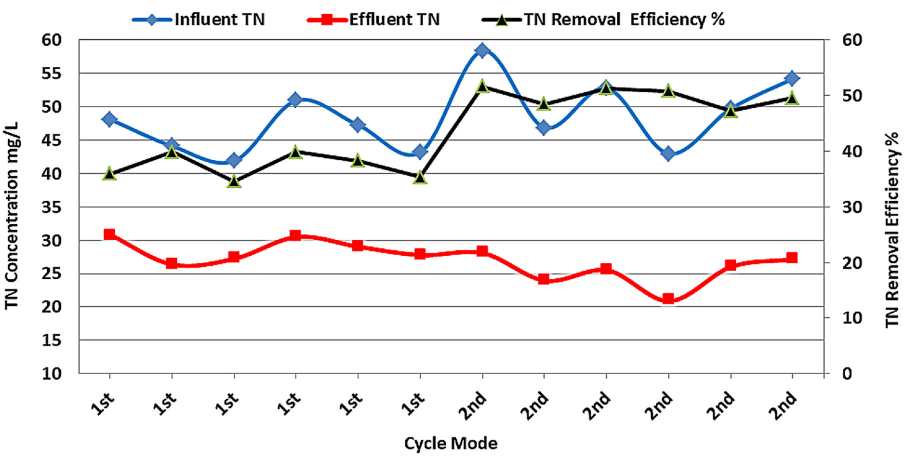

Figure 5. Input, output, and the elimination efficiency for total nitrogen under various operating cycle modes

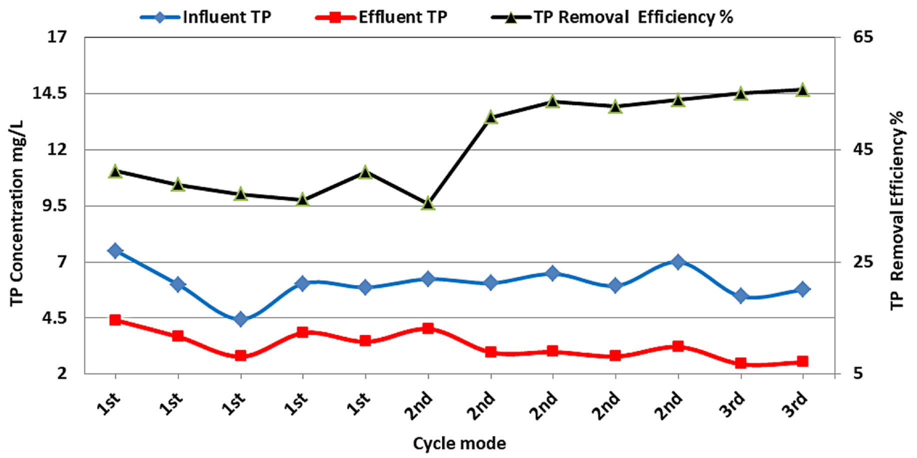

Figure 6. Input, output, and the elimination efficiency for total phosphorus under various operating cycle modes

Removal of total phosphorus at various operating cycle modes

Phosphorus in sewage can be verified through phosphates (orthophosphates), Polyphosphates, and organic phosphorus. Thus, this study section used the total phosphorus (TP) test, which measures all the forms of phosphorus mentioned previously in the sample. In oxidation ponds system, Arceivala (1981) and Van Haandel and Lettinga (1994) report that phosphorus is removed mainly by two processes: (1) phosphate precipitation at a high pH above eight and (2) its assimilation by aquatic organisms, mainly algae. Therefore, the TP concentration results are presented in Figure 6 and Table 2, which illustrate how input, output total phosphorus, and removal efficiency concentrations change with two different operating cycles. The TP concentration fluctuated throughout this work in the raw incoming, as shown in the table, during the system's operation under different cyclic modes to determine the best efficiency between enriched and non-enriched ponds. It can be observed that the concentration varied precisely between values 4.45 mg/L to 7.5 mg/L (mean = 6.07 with SD = 0.75), which is closer to the typical municipal wastewater limits mentioned by researcher von Sperling (2005), which were (4–15 mg/L); typical 7 mg/L and Metcalf and Eddy (2003), which were 4 to 16 mg/L.

In contrast, this pollutant's total effluent fluctuated between a minimum equal to 4.41 mg/L and a maximum equal to 2.46 (mean = 3.27 and SD = 0.62). During this crucial experiment phase, the results of operation cycles demonstrated that improving the pond system impacted the TP elimination efficiency and total concentration for outflow. The most striking effect was observed in the second operation cycle when the enhanced ponds improved the efficiency system. In contrast, using traditional pond systems during the first operation cycle mode led to a noticeable decrease in the multiple ponds' performance compared with the second cycle. It is noted that the elimination efficiency for the 1st cycle mode and the 2nd cycle mode was 38.26% (SD = 2.48) and 53.63% (SD = 1.74), respectively.

Removal of F. coliform in enriched ponds

Of course, treating municipal sewage using an enriched pond approach reduces pollutants in general. For pathogenic organisms, scientists identify indicator organisms like coliforms, mostly intestinal bacteria excreted through faeces, as the best indicators of water contamination by faeces, as their presence in water indicates the likelihood of pathogenic organisms (Soares, 1999). Generally, theories on removing thermotolerant coliforms in pond systems are unclear. Some factors, such as high pH values resulting from algae using carbon dioxide, the bactericidal effect of sunlight, hydraulic detention time, sedimentation, dissolved oxygen, competition for nutrients, and the presence of predators, have been related as factors that influence the mortality rate and removal of thermotolerant coliforms in pond system (Liu et al., 2018). Therefore, through the examinations, which occurred in a warm time of year, it was observed that the value of an average of faecal coliform (F.C.) in the incoming flow sewage around 6.5×10^6, ranging from a minimum to maximum of 1.8×10^6 to 2.7×10^7 as *F. coliform* N/100 mL.

These values were lowered in the outflow to an average value of 1.0× 103 as *F. coliform* N/100 mL, leading to an average removal of a percentage of 99.98%. The enriched pond system's final effluent approximately complied with the recommended *F. coliform* count of less than 1000 per 100 ml for unrestricted irrigation.

CONCLUSIONS

Lab-scale experiments on stabilization ponds have been achieved to examine the feasibility of enriching them with activated sludge to improve their performance in removing pollutants, especially nitrogen and phosphorus. Throughout the continuous experimental operation, the potential for the enriched pond's decomposition activity was always superior to that of the un-enriched pond. Results show that the COD, NH_4^+-N, TN, and TP efficiency for enrichment ponds is 89.92%, 91.45%, 49.58%, and 53.63%, respectively. Compared with conventional ponds, these rates are 71.58%, 75.93%, 37.32%, and 38.26%, respectively. The enriched pond system also achieved high removal for *F. coliform*, reaching 99.98%. The work results demonstrate that acceptable effluent quality could be anticipated in such an acclimatized system.

REFERENCES

1. Abdel-Shafy, H.I., Anwer, S., Hassan, S., Yahia, T. (2003). Risk assessment of sewage reuse on the sandy soil of Abu-Rawash Desert, Egypt. J. Environ. Prot. Engin., 29(1), 5–19.
2. Abdel-Shafy, H.I., Salem, M.A.M. (2007). Efficiency of oxidation ponds for wastewater treatment in Egypt. In: Wastewater Reuse-Risk Assessment, Decision-Making and Environmental Security (M. K. Zaidi, Ed.). Springer Publisher, The Netherlands, 175–184.
3. Al Baz, I., Otterpohl, R., Wendland, C. (2008). Efficient Management of Wastewater and Reuse in Water Scarce Countries. Springer, The Netherlands.
4. APHA, AWWA, WEF. (2005). Standard methods for the examination of water and wastewater. APHA, Washington, cDC, USA, 21st edition, 2005
5. Arceivala, S.J. (1981). Wastewater treatment and disposal. Marcel Dekker, New York, 892 p.
6. Avelar, F. J., Martínez-Pereda, P., Thalasso, F., Rodríguez-Vázquez, R., Alba, J., Esparza-García, F. J. (2003). Phenol Removal in Upgraded Facultative Waste Stabilisation Ponds. Environ. Technol., 24(4), 465–470.
7. Avelar, F.J., Martínez-Pereda P., Thalasso, F., Rodríguez-Vazquez, R., Esparza-García, F.J. (2001). Upgrading of facultative waste stabilisation ponds ander high organic load. Biotechnol. Lett., 23(14), 1115–1118.
8. Awad, A.M., Ibrahim, H.T., Al-Aboodi, A.H. (2023). Performance of Compact Bio-contact oxidation reactors for municipal wastewater treatment under different hydraulic retention time. Journal of Ecological Engineering, 24(12), 304–318.
9. Awad, A.M., Ibrahim, H.T., Al-Aboodi, A.H. (2024). Study on the start-up phase of the stabilization lagoons system for municipal wastewater treatment. Journal of Ecological Engineering 2024, 25(5), 351–366.
10. Babu, M., Hes, E.M.A., Vander Steen, N.P., Hooijmans, C.M., Gijzen, H.J. (2011). Nitrogen mass balances for pilot-scale biofilm stabilization ponds under tropical conditions. Bioresour. Technol., 102(4); 3754–3760.
11. Barjenbruch M., Erler C. (2005). A performance review of small German WSPs identifying improvement options. Water Sci. Technol., 51(12), 43–49.
12. Bassuney, D., Tawfik, A. (2017). Baffled duckweed pond system for treatment of agricultural drainage water containing pharmaceuticals. Int J Phytoremediation., 19(8), 774–780.
13. Bitton, G. 1999. Wastewater Microbiology. Wiley-Liss, Second Ed.
14. Colin, M., Ragush, J.J., Schmidt, W.H., Krkosek, G.A., Gagnon, L.T., Rob, C.J. (2015). Performance of municipal waste stabilization ponds in the Canadian Arctic. Ecol Eng., 83, 413–421
15. Crites R., G. Tchobanoglous. (1998). Small and Decentralized Wastewater Management Systems. New York, NY: McGraw Hill.
16. Destro, C.A.M., Amorim, R. (2007). Evaluation of the performance of the stabilization pond system in the CPA III neighborhood in Cuiabá/MT, based on physical-chemical and biological variables. In: Symposium on Water Resources of the North And Central-West, 1, 1. [Annals...]. (in Portuguese)
17. Dias, D.F.C., de Matos, M.P., Passos, R.G., Rodrigues, V.A.J., Von Sperling, M. (2017). Upgrading and evaluation of a simple pond system for small communities with simple interventions to reduce land requirements and increase performance. Wat Sci Technol., 12(1), 1–11.
18. Driscoll, C., Whitall, D., Aber, J., Boyer, E., Castro, M., Cronan, C., Goodale, C.L., Groffman, P., Hopkinson, C., Lambert, K., Lawrence, G., Ollinger, S. (2003). Nitrogen Pollution in the Northeastern United States: Sources, Effects, and Management

Options. *Bioscience*, 53(4), 357–374.

19. DWA. 2010. Wastewater Risk Abatement Plan: A Guideline to Plan and Manage Towards Safe and Compliant Wastewater Collection and Treatment in South Africa. Assessed 21 March 2014.
20. Faleschini, M., Esteves, J.L., Valero, M.A. (2012). The effects of hydraulic and organic loadings on the performance of a full-scale facultative pond in a temperate climate region (Argentine Patagonia). *Water Air Soil Pollut*, 223(5), 2483–2493
21. Gray, N.F. (1989). Biology of Wastewater Treatment. Oxford University Press, Oxford.
22. Hobus, I., Hegemann, W. (2001). Autonomous renewable energy systems for decentralized wastewater treatment. Hamburg Reports on Urban Water Management for Wastewater Management and Water Resources, 21, 11–18, 19–20.
23. Hussein, A. (2023). Textile wastewater treated by constructed wetlands – a critical review. *Journal of Ecological Engineering*, 24(5), 256–275
24. Jordão, E. P., Pessôa, C. A. (2011). Domestic sewage treatment (6 ed.). Brazilian Association of Sanitary and Environmental Engineering Rio de Janeiro: ABES. (in Portuguese)
25. Khan, S., Melville, B.W., Muneer, K.M., Shoaib, M., Shamseldin, A. (2017). Effect of baffles on the hydraulic performance of sediment retention ponds. *Water Sci Technol*, 75(9), 3725–3735.
26. Liu L., Hall G., Champagne P. 2018. Disinfection Processes and mechanisms in wastewater stabilization ponds: A review. *Journal of Environmental Reviews,* 26(4). https://doi.org/10.1139/er-2018-0006.
27. Long, T.H., Wout, V.E., Peter, L.M.G. 2017. Design of waste stabilization pond system: A review. Water Res., 123, 236–248.
28. Mama, C.N., Agunwamba, J.C. (2011). Laboratory study of the effect of temperature changes on mixing and performance of ponds. *Nigerian Journal of Technology*, 30(1).
29. Mara, D.D. (2007). Reuse of wastewater for irrigation. Sustain. *Water Manage*, 2, 20–22.
30. Mara, D.D., Mills, S.W., Pearson, H.W., Alabaster, G.P. (2018). Waste stabilization ponds: a viable alternative for small community treatment systems. *Water and Environment Journal*. https://doi.org/10.1111/j.1747-6593.1992.tb00740.x, 2018.
31. Moumouni, D.A., Andrianisa, H.A., Konaté, Y., Ndiaye, A., Maïga, A.H. (2015). Inactivation of Escherichia coli in a baffled pond with attached growth: treating anaerobic effluent under the Sahelian climate. *Environ Technol*, 37(9), 1054–1064.
32. Murdoch, P.S., Baron, J.S., Miller, T.L. (2000). Potential effects of climate change on surface-water quality in North America. *Journal of the American Water Resources Association*, 36(2), 347–366
33. Muttamara S., Puetpaiboon U., 1997. Roles of baffles in waste stabilization ponds. *Water Sci Technol*, 35(8), 275–284.
34. Oliveira, S.M.A.C. 2006. Performance and reliability analysis of sewage treatment plants. 2006. 214 f. Thesis (Doctorate in Sanitation, Environment and Water Resources) – School of Engineering, Federal University of Minas Gerais, Belo Horizonte. (in Portuguese)
35. Ouedraogo, F.R., Zhang, J., Cornejo, P.K., Zhang, Q., Mihelcic, J.R., Tejada-Martinez, A.E. (2016). Impact of sludge layer geometry on the hydraulic performance of a waste stabilization pond. *Water Research*, 99; 253–262.
36. Pearson, H.W., Mara, D.D., Bartone, C.R. (1987). Guidelines for the minimum evaluation of the performance of full-scale waste stabilization pond systems. *Water Research*, 21(9), 1067–1075.
37. Playle, R.C., Wood, C.M., (1989). Water chemistry changes in the gill micro-environment of rainbow trout: experimental observations and theory. *J Comp Physiol B*, 159(5), 527–537.
38. Polprasert C., Agarwalla B.K. (1994). A facultative pond model incorporating biofilm activity. *Water Environ Res*, 66, 725–32.
39. Polprasert C., Sookhanich S. (1995). Upgrading of facultative ponds to treat a toxic organic wastewater. *Water Sci Technol*, 31, 201–210.
40. Preston, S.D., Alexander, R.B., Schwarz, G.E., Crawford, C.G., (2011). Factors affecting stream nutrient loads: A synthesis of regional SPARROW model results for the continental United States. *Journal of the American Water Resources Association,* 47(5), 891–915.
41. Rakkoed A., Danteravanich S., Puetpaiboon U. (1999). Nitrogen removal in attached growth waste stabilization ponds of wastewater from a rubber factory. *Water Sci Technol,* 40(1) 45–52.
42. Ramos M.S., Dávila J.L., Esparza F., Thalasso F., Guerrero A.L. and Avelar F.J. (2005). Treatment of wastewater containing high phenol concentrations using stabilization ponds enriched with activated sludge. *Water Sci. Technol*, 51(12), 257–260.
43. Rinhofer, B., Smith, M.D. (2010). An analysis of cascade-aerated facultative waste stabilization ponds in the United Kingdom. *Water Environ J*, 25(2), 290–295.
44. Sasani, H., Mehrdadi, N., Aminzadeh, N. and Takdastan, A. (2017). Baffle and fixed media effects on coliform removal and bacterial die-off rate coefficient in waste stabilization ponds (a case study in Ahvaz). *Environ Health Eng Manag*, 4(3), 177–184.
45. Shin H.K., Polprasert C. (1987). Attached-growth waste stabilization ponds treatment evaluation. *Water Sci. Technol*, 19, 229–235.

46. Silva, L. K. T.; Soua, M. A. G.; Pires, A. D. M.; Lima, K. S.; Albuquerque, B. C. D.; Araujo, A. L. C. (2010). Preliminary evaluation of nutrient removal efficiency in three stabilization pond systems in the State of Rio Grande do Norte. Anais do CONNEPI, Aracaju, 2010. http://congressos.ifal.edu.br/index.php/connepi/CONNEPI2010/paper/viewFile/893/617. Access: 22.09.2015 (in Portuguese).
47. Soares, J.B. (1999). Water, pollution and diseases. ABASTECE Magazine: Our water,.... I worry. ABAS, year 1, n. 1. January/February/March, Ceará, 26 p. (in Portuguese)
48. Thobanoglous G., Burton F.L., Stensel H.D. (2003). Wastewater engineering: Treatment, disposal and reuse (4 ed.), New York: McGraw Hill.
49. Van Handel, A.C. & Lettinga, G. 1994. Sludge treatment. In: Anaerobic sewage treatment, a problem for regions with hot climates. Campina Grande, Paraíba, Chapter 6.
50. Von Sperling, M., 2005. Introduction to water quality and sewage treatment (3 ed.). Belo Horizonte: DESA-UFMG. 243 p. (in Portuguese)
51. Wright, P., Heming, T., Randall, D. (1986). Downstream pH changes in water flowing over the gills of rainbow trout. *Journal of Experimental Biology*, 126(1), 499–512.
52. Zhao Q. and Wang B. 1996. Evaluation on a pilot-scale attached-growth pond system treating domestic wastewater. *Water Research*, 30, 242–245.