18th International Conference on Environmental Science and Technology

Athens, Greece, 30 August to 2 September 2023

Nitrogen & Phosphorous Removal via Anaerobic / Anoxic-Aerobic Processes and Struvite Formation in Mall Wastewater: Performance of Retrofitted Full-Scale Plants

MACEDA, MA. CLEOFAS O[1*], ROLLON, ANALIZA P.[2,*], SINOY, MA. CONCEPCION A.[3*]

[1] Environmental Engineering Graduate Program, University of the Philippines Diliman
momaceda@up.edu.ph

[2] Program Coordinator, Environmental Engineering, Professor Department of Chemical Engineering, College of Engineering, University of the Philippines Diliman
aprollon@up.edu.ph

[3]R&D Manager, JC DOTS Agri Trading; Professor – Lecturer 1, EnE Program, College of Engineering, University of the Philippines Diliman
conniealvior@gmail.com

Abstract

With the new standards on nitrogen (N) and phosphorous (P) in wastewater discharges from industrial, commercial and municipal wastewater, there is a need for better wastewater treatment systems. Moreover, with the presence of such N and P in wastewater, struvite formation leading to clogging of pipes has also been a problem in wastewater treatment systems. This study aimed to improve N and P removal from mall wastewater through retrofitting with the inclusion of anaerobic/anoxic process prior to the existing aerobic process and recirculation of part of the effluent from aerobic process to anoxic tank in order to achieve ammonification of organic nitrogen, nitrification and denitrification in the whole system. The recovery of struvite, which is magnesium ammonium phosphate (MgNH4PO4), is also expected to be another pathway via which N and P can be removed from the wastewater. Seven mall wastewater treatment plants were monitored. Both the previous and new system include chlorination as a final treatment. The treatment performance with respect to the removal of N and P of the new retrofitted system is better than the system where the biological treatment process was mainly aerobic. Better levels of organic matter, oil and grease, total suspended solids (TSS), surfactant and fecal coliform were also achieved. The levels of N and P in the effluents of the anaerobic/anoxic process has become so low that precipitation of struvite via magnesium dosing is not feasible. Struvite formation already occurs at the mixing tank after anaerobic/anoxic tank. The new wastewater treatment system, with reduced aeration requirements, where N and P were removed by nature based bacteria and without the use of large dose of chemicals becomes a cost-effective solution for a cleaner environment.

Keywords: anoxic, denitrification, nitrogen, mall wastewater phosphorous, mall wastewater, struvite

Introduction

Nitrogen is essential for life, and it is the fourth most abundant element in the biosphere. Domestic wastewater such as those coming from shopping malls always contains high concentrations of plant nutrients nitrogen and phosphorous (N & P) and therefore brings high nutrient load to receiving body of water. These nutrients are key factors that cause eutrophication of closed water systems and excessive growth of algae. Wastewater treatment plants must remove phosphorous and nitrogen compounds from the wastewater before its final disposal in order to prevent eutrophication. With the strict implementation of the Department of Environment and Natural Resources (DENR) of the Philippine Clean Water Act otherwise known as Republic Act 9275, about nitrogen content of effluents and other pollutants, new and more sustainable processes must be explored and developed.

Engineering solutions has been developed through the years in other countries. They specified aim to remove nitrogen from wastewater. The traditional biological nitrogen removal processes utilized in wastewater treatment systems involve biological oxidation of ammonium (NH1+) to nitrite and further to nitrite (NO3-), i.e., nitrification, and then followed by reduction of nitrates with an organic carbon source (obtained as part of the chemical oxygen demand, i.e., COD) to nitrogen gas (N2), i.e., denitrification. Both nitrification and denitrification possess nitrite (NO_2-) as an intermediate. Hence, if nitrification is stopped at nitrite (nitrification), then complete denitrification from nitrite to nitrogen gas can be achieved. Nitrogen removal via nitrite may yield up to a 25% reduction in aeration and 40% reduction in carbon source requirement for denitrification as compared to denitrification via nitrate. This reduction in carbon source requirement is particularly advantageous for wastewater having low COD/N ratio. However, there is difficulty in achieving specific inhibition or elimination of the nitrite oxidizing bacteria (those that oxidize nitrite to nitrate), while retaining ammonia oxidizing bacteria (those that oxidize ammonia to nitrate).

Struvite is magnesium ammonium phosphate ($MgNH_4PO_46H2O$), and forms a hard crystalline deposit when the molar ration Mg : NH_4 : PO_4 is greater than 1 : 1 : 1. This phenomenon has been found as early as 1939. Struvite is most likely to form in areas of increased turbulence, as its solubility is often associated with anaerobic and post digestion processes. This struvite formation provides a pathway for N and P removal.

Struvite formation is an alternative for the removal of nutrients from the aerobically digested liquor of shopping mall wastewater due to its high removal effectiveness, reaction rate, and solid-liquid separation capability (Huang et al, 2010). Crystallization of N and P in the form of struvite ($MgNH_4PO_46H_2O$) has been successfully used for nutrient removal and for obtaining a valuable fertilizer.

2. DENR issuance of new eflfuent regulations

The Philippine government through the Department of Environment and Natural Resoures – Environmental Management Bureau, sometime in 2016 issued and approved DAO 2016-08 and further amended sometime in 2021 as per DAO 2021-19, the additional stringent parameters in nitrate, phosphate, ammonia and surfactants, for compliance in the treatment of domestic wastewater. Said standards for Real Estate Industry are shown in Figure 1 below:

DAO 2016-08 & DAO 2021-19 new general effluent regulations

PSIC	Industry Category	Significant Parameters
56 & 37000	Restaurants, food chains, bars and other food/beverage services (with domestic sewage)	BOD, Total Suspended Solids, Oil and Grease, Surfactants + Fecal Coliform, Ammonia, Nitrate, Phosphate

Significant Parameters	DAO 1990-35 (Class C)	DAO 2016-08 (Class C)	REMARKS
BOD5, mg/L	50	50	no change
TSS, mg/L	70	100	more lenient
Oil and Grease, mg/L	5	5	no change
Surfactants, mg/L	5	15	more lenient
Fecal coliform, mg/L	--	400	new parameter
Ammonia as NH^3-N, mg/L	--	0.5/4	new parameter
Nitrate as NO_3-N, mg/L	--	14	new parameter
Phosphate, mg/L	--	1/4	new parameter

Figure 1. DAO 2016-08 & DAO 2021-19 effluent standards for Real Estate Industry

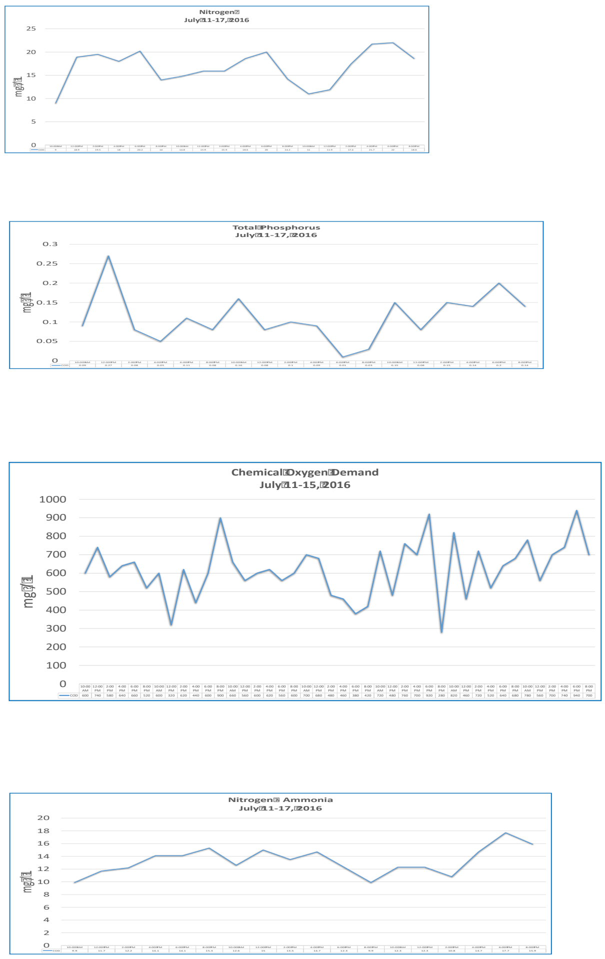
3. Retrofitting of all existing 27 Sewage Treatment Plants (STP)

3.1 Baseline data laboratory analysis of domestic wastewater

In order to come up and propose the right cost effective design flow rate to comply the new effluent regulations, a baseline data gathering was conducted for the influent domestic wastewater coming from a shopping mall, the subject of the study. Samples from influent of STP were collected every two hours for quantitative laboratory analytical. The results shows a very low characteristics in terms on nitrate, phosphate and ammonia, as shown Figures 2 below:

Figure 2. shows the analytical laboratory analysis of influent in the parameter on nitrate, phosphate, ammonia, phosphorous and chemical oxygen demand, which all shows a low contents of nutrient for domestic wastewater.

Characteristics of Domestic Wastewater - INFLUENT



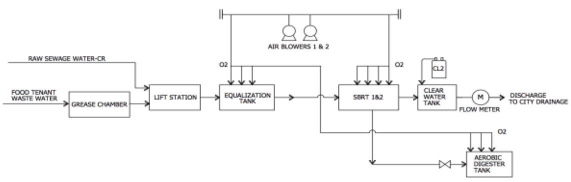
4. STP Retrofitting Process Flow Design

4.1 Existing STP process flow design implementted

Figure 3 below shows the aerobic sequencing batch reactor process flow design for existing Sewage Treatment Plants of the commercial shoppong malls.

Figure 3. Old System Process Flow Design – SBR System

Old System Process Flow Design – SBR System



5. Struvite Minimization Study in the pilot bench scale model

In order to minimize and remove the nutrients, a bench scale model was installed treating the raw influent coming from the shopping mall wastewater, to conduct study on how to recover struvite or magnesium ammonium phosphate. Below is Figure 4. Struvite reaction before anoxic.

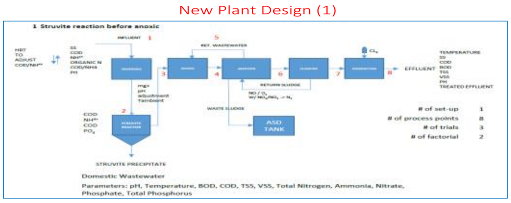


Figure 4. Experimental design for struvite reaction before anoxic.

Figure 5 below shows the process flow on the struvite reaction after anoxic.

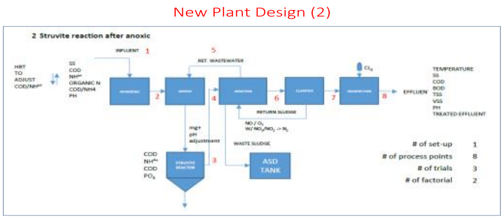


Figure 5. Experimental design for struvite reaction after anoxic.

6. Process Flow Design formulated to comply DAO 2016-08 and DAO 2021-19

6.1 Figure 6 below is the process flow design that was formulated and a product of the actual pilot plant design in struvite recovery, to remove the nutrients.

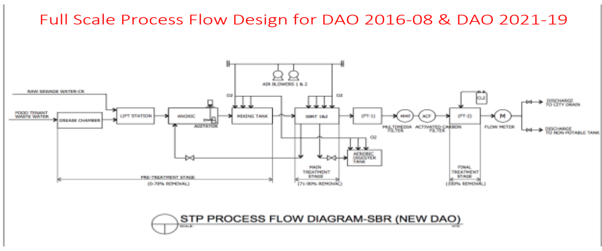
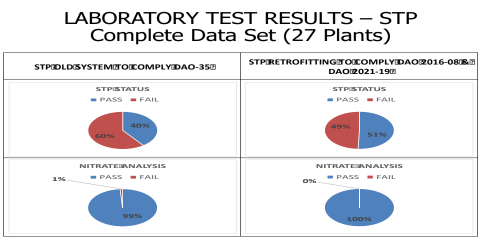


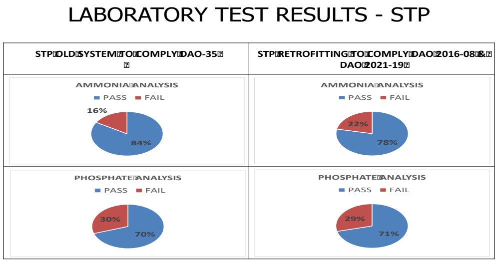
Figure 6. Full Scale Process Flow Design in compliance DAO 2016-08 & DAO 2021-19

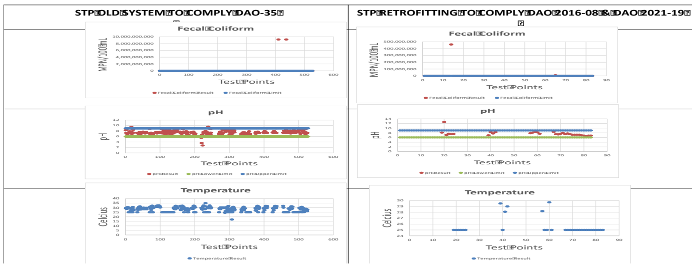
6.2 STP Laboratory Results of the STP Retrofitted using the Process Flow Design for DAO 2016-08 & DAO 2021-19

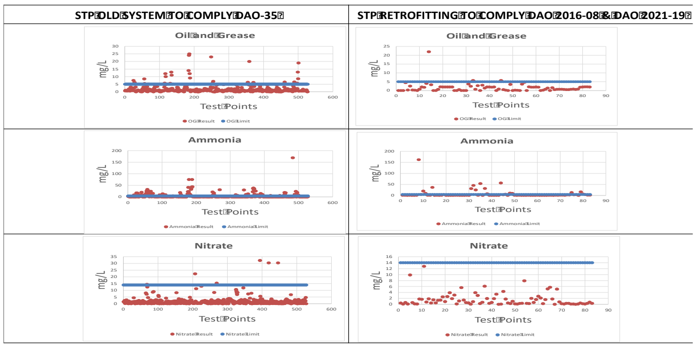
The results of analytical laboratory analysis of the retrofitted STP effluent using the process flow design in compliance of DAO 2016-08 and DAO 2021-19 were all passing the new general effluent regulations.. Figure 7 below, shows the results of full scale plants effluent laboratory analyses.

Figure 7. Laboratory results of full scale effluent plant design in compliance to DAO 35; and in compliance to DAO 2016-08 & DAO 2021-19.









Since implementation of STP Retrofitting of Shopping Malls in this study, passed test results improved from 5.67% to 49.65%. This implies that quantity of passed test results versus failed test results improved by 4/23 or 0.17 to 69/121 or 0.57. This is an improvement by as much as 235.29%.

7. Circular economy from struvite recovery

The recovery of nutrients has resulted of a circular economy by way of using the recovered struvite as fertilizer, which, in turn has potentially reduced possible eutrophication rate in the receiving water body. This process will then give a new development of new emerging market for possible revenue stream from fertilizer.

8. Conclusions & Recommendations

Given the number of plants installed and retrofitted to make them compliant with the said legal regimes, the more compelling reason of intervening to convert the plants to be compliant overrode the desire to fully understand the formation of struvite, which is the mineral of interest; the elimination took priority over the formation. But the pilot plant of the original dissertation proposal was the reference and guidance in coming up the final process flow design to retrofit the STPs and for new projects, to comply the new effluent regulations as per DAO 2016-08 and DAO 2021-19.

The data collected from DAO-35 era vs DAOs 2016-08 & 2012-19 plants have been analyzed; there was an overall improvement of values found in the latter, and all non-compliant values were dealt with accordingly.

The opportunity of by-passing the use of a pilot plant for experimentation by prototyping and optimizing in full-scale plants presented itself when retrofitting the plants and observing a general improvement in practically all parameters measured for compliance.

The reliance on tried and tested flowsheets, and improving on them, became the key element in solving the problem on struvite formation in the plants; the inclusion of a return loop from aeration tank transporting the wastewater to anoxic tank, is the reason for the virtual elimination of the mineral, and thus, passing the standards on the parameters on nitrate, phosphate and ammonia.

Since every plant had unique water analyses, the measured parameters – on top of temperature, pH, and coliform content, presented unique challenges in the objective of making the plant compliant in all said parameters.

There was an effort to form struvite on a bench scale with a synthetic mix using Mg : N : P is 1 : 1 : 1; the main problem encountered was the difficulty in bringing the pH level to alkaline, where crystallization of struvite is supposed to happen. It was though that there might be buffering ion in the "wastewater" used even if it should be simpler, as least on water analysis, than actual wastewater from the malls or other sources. To address, it has been planned to use wastewater taken from actual plants, and perhaps from a piggery, as it is suspected that the Nitrogen is the critical element that is necessary for struvite formation, even if the ratio of Mg : N : P is suppoed to be 1 : 1 : 1.

Phosphorous (P) plays an essential role in the metabolism of living organisms; and it is incapable of being replaced as nutrient in food and feed production. Unlike Nitrogen that is abundant in the natural environment, the supply of primary P is limited from phosphate rock deposits. Struvite deposition is a natural occurrence in WWTPs, and clogs pipes and scaling, resulting in high operating and maintenance costs. Hence, future study is recommended on the recovery of struvite from wastewater to be used as raw material in the production of fertilizer; while at the same time, wastewater treatment system is optimized to comply the stringent new general effluent regulations of the DENR.

The formation of struvite in the sewage treatment plant reduced the phosphate and also ammonium concentrations, which in turn fulfill and complied the new general effluent standards as per DAO 2016-08 and DAO 2021-19, and control and avoid eutrophication of the water receiving body.

Future study is recommended to optimize HRTs and organic loading rates. As a way forward, said use of actual wastewater will be made instead of the earlier synthetic mix, and to possibly apply for patent the process flow designed formulated in this study.

9. References:

Adhena Ayaliew Werkneh, Shifare Berhe Gebru, Development of ecological sanitation approaches for integrated recovery of biogas, nutrients and clean water from domestic wastewater, Resources, Environment & Sustainability, Vol 11, March 2023, 100095

Bing Li, Haiming Huang, Zhitao Sun, Ning Zhao, Tajammal Mumir, Wei Yu, Brent Young, Minimizing heavy metals in recovered struvite from swine wastewater after anaerobic biochemical treatment: Reaction mechanisms and pilot test, Journal of Cleaner Producton, Vol 272, 1 November 2020, 122649

DENR Administrative Order No. 2016-08 & DENR Administrative Order 2021-19, New General Effluent Regulations

Md. Saifur Rahaman, Donald S. Mavinic, Alexandra Meikleham, Naoko Ellis, Modeling phosphorus removal and recovery from anaerobic digester supernatant through struvite crystallization in a fluidized bed reactor, Water Research, Vol 51, 15 March 2014, Pages 1-10

P. Achilleos, K.R. Roberts, I.D. Williams, Struvite precipitation within wastewater treatment: A problem or a circular economy opportunity?, Heliyon Journal, Vol 8, Issue 7, July 2022, e09862

Soni Kumari, Sheeja Jagadevan, Phosphorus recovery from municipal wastewater through struvite biomineralization using model gram-negative and gram-positive bacterial strains, Journal of Cleaner Production, Vol 366, 15 September 2022, 132992

Yangjie Qin,Kaichong Wang , Qing Xia , Siqi Yu , Maonan Zhang , Ying An , Xiaodan Zhao , Zhen Zhou, Up-concentration of nitrogen from domestic wastewater: A sustainable strategy from removal to recovery, Chemical Engineering Journal, Vol 451, Part 3, 1 January 2023, 138789

Yingxue Li, Defu Xu, Haizhi Lin, Wenhua Wang, Hong Yang, Nutrient released characteristics of struvite-biochar fertilizer produced from concentrated sludge supernatant by fluidized bed reactor, Journal of Environmental Management, Volume 325, Part A, 1 January 2023, 116548

Yu-Jen Shih, Ralf Ruffel M. Abarca, Mark Daniel G. de Luna, Yao-Hui Huang, Ming-Chun Lu, Recovery of phosphorus from synthetic wastewaters by struvite crystallization in a fluidized-bed reactor: Effects of pH, phosphate concentration and coexisting ions, Chemosphere, Vol 173, Aprl 2017, Pages 466-473