Performance evaluation and upgrade options for existing sequencing batch reactor for nutrient removal

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Abstract. Assessment and upgrade of existing sewage treatment plants (STPs) are necessary due to the revision of the existing effluent regulations which now monitors nutrients including ammonia, nitrate and phosphates. The aim of this study is the performance evaluation of four sequencing batch reactor (SBR) type of STP based on the following parameters: biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), nitrates, ammonia, phosphates and pH; and their potential upgrade based on the revised regulations stated in DAO 2016-08. Four sequencing batch reactor (SBR) type of STP were assessed for 12 weeks for this study. Results showed noncompliance with nutrient levels, thus upgrade is necessary. Analytical Hierarchy Process (AHP), a Multi-Criteria-Analysis (MCA) tool, was used to select the best option for upgrade among options that include (1) additional SBR tank, (2) diverting wastewater to another treatment facility, and (3) converting the SBR into membrane bioreactor (MBR). Considering the criterion for upgrade, option 2 was the most preferred decision followed by option 1 then option 3.

1 Introduction

Daily routines such as bathing, cooking and washing generate wastewater **[1]**. If wastewater is left untreated and allowed to accumulate, it can potentially cause diseases to spread and pollute the environment.

Treating of wastewater is necessary and is required by the law. Discharge standards in the Philippines are recently updated and are stated in Department of Environment and Natural Resources (DENR) Administrative Order No. 2016-08 **[2]** . **Table 1** shows the effluent standards for Inland Waters or Class C as stipulated in DAO 2016-08. The updated standard is a revision of DAO 1990-35 **[1]** with values as upper limit for the same class of wastewater included also in Table 1. Effluent values shown in the table for DAO 1990-35 is for old or existing industry (OEI).

Table 1. Effluent Quality Standards for Class C Inland Waters

Parameter	DAO 1990-35 (OEI)	DAO 2016-08
BOD	80	50
COD	150	100
TSS	90	100
Nitrates	-	14
Ammonia	-	0.5
Phosphates	-	1
pH	6.0-9.0	6.0-9.5

As shown in the table, DAO 1990-35 does not contain limits for nutrients such as ammonia, nitrates and phosphates. High amount of nutrients in the water will lead to eutrophication whereby the increase in nutrients level causes excessive algae and plankton growth thus depriving the water species of oxygen resulting to death of these animals **[4]**

Wastewater treatment plant (WWTP) or Sewage Treatment Plant (STP) is used in treating of wastewater. Different institutions in Manila, Philippines usually uses sequencing batch reactor (SBR) type in their treatment facilities. SBR type of STP removes biochemical oxygen demand, suspended solids, phosphorus and nitrogen. It treats the water by using microorganisms to mineralize the particulate organics **[5]**. The existing SBRs in Manila were originally designed to comply only with the old effluent standard. In order to comply with the new standards, upgrade of these treatment facilities is necessary.

The aim of this study is to monitor compliance of four selected STPs with the standards stated in DAO 2016-08 including COD, TSS, nitrates, phosphates and ammonia; and to conduct simple multi criteria analysis of several options for upgrading the existing four selected STPs based on the results of the parameters monitored.

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2 Materials and methods

2.1 Experimental Set-up

Four SBR type of STPs were selected from an institution for this study. This experiment focused on monitoring the effluent of the STPs with compliance to DAO 2016-08. The design and operating characteristics of each STP are presented in **Table 2**.

Table 2. Design and operating characteristics of STPs

STP	Cycles [hr/batch]	Batches/ Day	Blower Flowrate [m³/min]	Motor [hp]
1	6	4	6.92	5.5
2	4	6	5.6	3.7
3	4	6	6.45	15
4	4	6	4.56	7.5

The systems were continuously monitored for a period of twelve weeks. The samples were gathered from the SBR tank effluent of the four STPs. Two more sample points were conducted on STP 1, the influent and the effluent after post-treatment to check the percent removal.

2.2 Analytical methods

The samples were analyzed for their corresponding parameters right after sampling. Analysis methods for the parameters are mentioned in **Table 1**.

The 5-Day BOD test was performed according to the standards by a third-party laboratory. The rest were done based on the HACH standard method of analysis including HACH Oxygen Demand [6], HACH Nitrate [7], HACH Nitrogen [8] and HACH Phosphorus [9].

2.3 Multi-criteria analysis

The data obtained from the analyses of samples shows the areas of improvement for each STP. Improvement may be done through various upgrades and in order to have feasible options, Analytical Hierarchy Process (AHP) is used for its multi-criteria analysis (MCA).

AHP is a decision-making tool and can be applied in various situations and fields [10]. The criteria that were considered are the technical aspect (TA), environmental aspect (EA), cost (C), and ease to upgrade (EU). A survey questionnaire was made in the manner that the responses may be used for the calculation of weights to be allotted for each criterion. The resulting analyses were the options suggested for the improvement of the system.

3 Results and discussion

3.1 Wastewater Characterization

Data gathered for BOD for STP 1 is shown in **Fig.** 1. It ranges from 27 mg/L to 81 mg/L.

Fig. 1. Biochemical oxygen demand (BOD)

The results obtained for COD, TSS, nitrates, ammonia, phosphates and pH are at 41-351 mg/L, 0.67-120.67 mg/L, 0.86-73.63 mg/L, 0-21.43 mg/L, 0.57-28.62 mg/L, and 2.64-7.49, respectively. These values are illustrated in Figure 5. The standard for each parameter is depicted with a straight red line.

The BOD samples were only taken at the influent and effluent of STP 1 and were only analyzed for four weeks. Out of the four trials, the effluent of STP 1 only complied once.

For COD, each STP showed different performance. STP 3 had the highest compliance percentage of 75% followed by STP 2 with 58%. On the other hand, the SBR tank effluent and final effluent of STP 1, achieved 8% and 25% compliance respectively. In addition, the STP 4 showed only 33% compliance.

In terms of TSS, STP 2, STP 3 and STP 1 Effluent showed 100% compliance while STP 4 showed 92% compliance. This is the only parameter that consistently complies with the standards.

Similar to COD, STP 3 is the only facility that showed 100% compliance for the nitrogen in the form of nitrate standard. STP 2 complied 50 of the time and showed low deviation while the STP 1 Effluent complied 8% of the time. STP 4 and STP 1 SBR Effluent showed incompliance for the whole duration of the experimental study.

In terms of ammonia, out of four STPs, only STP 2 was able to show compliance 50% of the time. As for phosphates, STP 4, STP 1 SBR Effluent and STP 1 Effluent showed 0% compliance while both STP 2 and STP 3 showed 8% compliance.

For pH, only STP 3 was able to achieve 100% compliance. Most of the SBR Effluent were acidic in nature. The compliance percentage of STP 2, STP 1 SBR Effluent, STP 3 and STP 1 Effluent are 58%, 50%, 42% and 25%, respectively.

The compliance percentages of the STPs are summarized in **Table 3**. Non-compliance is more common than compliance. This is somehow expected since there are defects in the control system of the
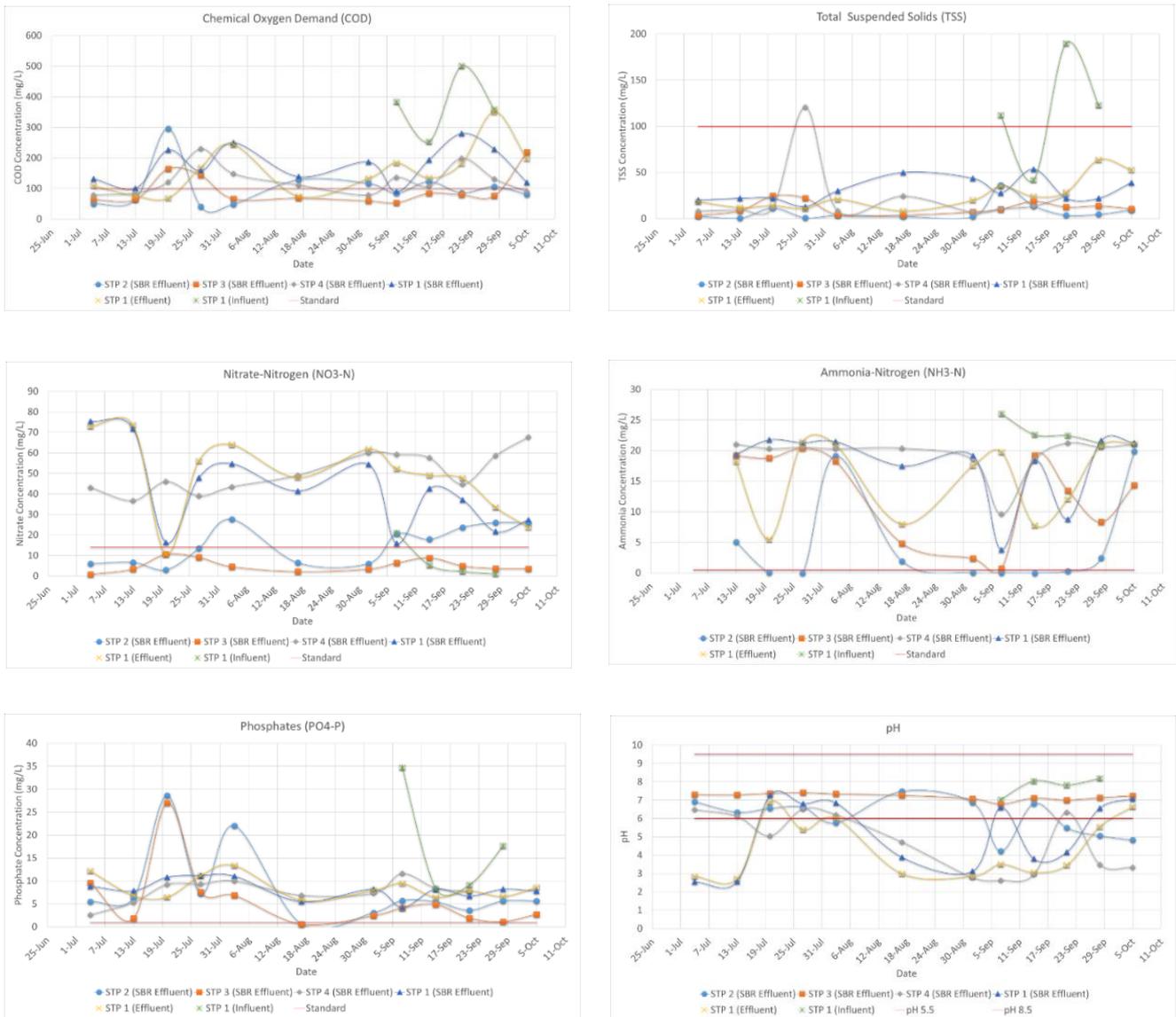
Fig. 2. COD, TSS, Nitrate-Nitrogen (NO$_3$-N), Ammonia-Nitrogen (NH3-N), Phosphates (PO4-P) and pH.

facilities. The inconsistency of data may also be due to irregular volume of flow entering the facilities.

Table 3. Compliance percentage of the STPs

Parameter	STP 1		STP 2	STP 3	STP 4
	Final Effluent	SBR Tank Effluent	SBR Tank Effluent		
BOD	8%	-	-	-	-
COD	25%	8%	58%	75%	33%
TSS	-	100%	100%	100%	92%
Nitrates	8%	0%	50%	100%	0%
Ammonia	0%	0%	55%	0%	0%
Phosphates	0%	0%	8%	8%	0%
pH	25%	50%	58%	100%	42%

3.2 Percent removal efficiency

The performance of the STP may also be evaluated by its removal efficiency. STP 1 was selected for this and was evaluated for four consecutive weeks in terms BOD, COD, TSS, ammonia-nitrogen and phosphates.

The results of the removal efficiencies for STP 1 are summarized in **Table 4**.

Table 4. Percent Removal Efficiency of STP 1

	BOD	COD	TSS	NH$_3$-N	PO$_4$-P
%Removal	54.46	57.14	77.91	28.11	26.17

Generally, the removal efficiencies were comparatively low with respect to the literature data for SBR wherein the BOD, TSS and biological phosphorous percent removal are at 89-98%, 85-97% and 57-69% **[11]**, respectively. Thus, STP 1 was showing poor performance.

3.3 Inter-parameter effect

There are several factors that may affect the quality of wastewater in a STP. These includes pH, temperature, retention time and mixing **[12].** pH affects the population of bacteria. An optimum range is necessary because a value too high or too low slows down the biological processes and may kill the bacteria. Changes in pH may

be brought about by the varying activities in a building; for example, the use of muriatic acid or other chemicals for cleaning lowers the pH. Therefore, pH should be properly maintained by the operator.

Similar to pH, the temperature should be within a certain range since biochemical reactions are dependent of temperature. Cold temperature slows down the rate of reaction while warmer temperatures do otherwise. The maintenance of proper retention time is necessary because leaving wastewater within the reactor for long periods of time causes the bacteria to spoil. Moreover, when the bacteria within the system metabolizes, the pH decreases which cause the death of the bacteria. Lastly, wastewater should be properly mixed in order to distribute food and oxygen evenly within the system.

3.4 Multi-criteria analysis (MCA)

Considering the results of the performance evaluation of the STPs, three options were considered for the improvement of the effluent quality: (1) addition of an SBR tank, (2) diversion of wastewater to a different treatment facility and (3) converting the SBR into Membrane Bioreactor (MBR).

The first option is the addition of one tank for each facility to accommodate additional hours in a cycle. Currently, the STP 2, STP 3 and STP 4 cycles last 4 hours per batch while STP 1 lasts for 6 hours per batch. Enough aeration time is necessary in order to convert the nutrients to acceptable end products [13]. Since the volume of amount of wastewater coming in the treatment facility cannot be controlled, sometimes the cycle times are shortened in order to accommodate all wastewater influent. To ensure that the proper aeration time is obtained, an additional tank may be installed. This option will accommodate bigger volume of wastewater, but it will require an additional space.

Overcapacity may also be resolved using the second option: diverting of the excess wastewater from the other STPs to STP 1 since the latter is not in full capacity. Occasionally, low volume of influent becomes a problem in STP 1. This option will not only solve both the overcapacity issues of the rest of the plants, but it will also address the issue encountered by STP 1. Moreover, this option would only require changes in the piping system.

Lastly, the third option is to divide the SBR tank into two, retain the first half as SBR and convert the second half into a Membrane Bioreactor (MBR) Tank. An MBR has higher removal efficiency than SBR, but is more expensive. It is more effective in treating wastewater, but requires higher maintenance in terms of operator skills and cost.

Each option provides advantages and disadvantages. The AHP showed the best option for the improvement of the wastewater treatment system of the institution.

The responses from the survey questionnaire are product of the opinion of experts on the field of wastewater treatment technology. An overall geometric mean is computed to obtain average out of the responses

of the expert allotted for each criterion. Table 5 show the computed weighted average for the four criteria by AHP.

Table 5. Computation for criteria weights

	TA	EA	C	EU	Sum	Eigen vector	Weight
TA	1.00	1.00	0.20	1.73	3.93	0.12	0.12
EA	1.00	1.00	0.11	1.00	3.11	0.10	0.09
C	5.00	9.00	1.00	5.91	20.91	0.68	0.67
EU	0.57	1.00	0.16	1.00	2.74	0.08	0.09
				Total	30.70	1.00	1.00

The weights are computed by repeating the method of AHP on the matrix four times. From the final computation table for criteria, the overall response shows that the cost is the most important factor for choosing the method of improvement of the process. The difference is large between the weight of the cost criterion and the weight of the next criterion, the technical aspect. The least important criteria in choosing the option is the ease to upgrade. The data is found to be consistent with the standards found by Saaty [10]. The consistency index is 0.02 and the random index is 0.9 due to a 4x4 matrix. The consistency ratio is computed to be 0.023 which is considered consistent since it is lower than 0.2. With these values, the weights for the decision based on each criterion is to be found next.

Table 6 below shows the summary of criteria and decision weights for the three options considered for the study.

Table 6. Summary of criteria and decision weights

Option	TA	EA	C	EU	Final Rating
Option 1	0.43	0.17	0.20	0.24	0.23
Option 2	0.48	0.17	0.73	0.69	0.64
Option 3	0.07	0.65	0.05	0.05	0.11
Criteria	0.12	0.09	0.67	0.09	

The table shows that among the three options, option 2 is considered as the least costly, given that it will only entail change in piping, while the first option will need additional construction for a tank and the third option requires acquisition of membrane. When the technical aspect is considered, option 2 was the most preferred. This result was obtained because SBR is widely used already while the MBR came in only at around 1960s. This may have also been the case for the ease-to-upgrade criteria. With respect to environmental aspect, however, option 3 is the most preferred given that MBR has a higher removal efficiency compared to SBR. The final rating of the decisions based on the criteria are obtained and option 2 is the most preferred out of the three options followed by option 1, and followed by the least preferred, option 3.

4 Conclusion

The study focuses on monitoring and performance evaluation of the STPs in an institution using HACH and standard methods for analysis. Data gathered showed ranges for BOD, COD, TSS, nitrates, ammonia, phosphates and pH at 27-81 mg/L, 41-351 mg/L, 0.67-120.67 mg/L, 0.86-73.63 mg/L, 0-21.43 mg/L, 0.57-28.62 mg/L, and 2.64-7.49. Results showed noncompliance with nutrient levels.

Influent samples were obtained for four weeks in STP 1 making it possible to monitor its removal efficiency. The STP 1 show removal efficiencies of 54.46%, 57.14%, 77.91%, 28.11% and 26.17% for BOD, COD, TSS, ammonia, and phosphates, respectively. These removal efficiencies were comparatively low with respect to the literature data for SBR; thus, STP 1 was showing poor performance.

There are several factors that may affect the quality of wastewater in a STP. These include pH, temperature, retention time and mixing. pH and temperature affect the population of bacteria and biochemical reactions within the system. An optimum range is necessary because a value too high or too low slows down the biological processes and may kill the bacteria. pH should be properly maintained by the operator.

In order to improve the performance of the STPs, the group listed three options possible: (1) installment of a new tank in addition to the existing one to increase the cycle time, (2) diversion of the excess wastewater from STP 2, STP 3 and STP 4 to STP 1 and (3) conversion of SBR tank to Membrane Bioreactor (MBR) Tank. Analytical Hierarchy Process (AHP) was used for Multi-Criteria Analysis (MCA) to determine the best option for improving the current STP system. Out of the three options, option 2 was the most preferred followed by option 1 then option 3.

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