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Study of Pollutant Removal in Activated Sludge Process Using Lab Scale Plant by Intermittent Aeration

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Abstract — The present study was aimed at studying the removal of carboneous and nutrient pollutant from wastewater by intermittently aerating the lab scale activated sludge process. The process was conducted for varying cycle time and aeration fraction with same HRT, SRT and MLSS. The study found that the removal of COD, TKN and TP increases with increasing cycle time. COD and TKN removal decreasing with increasing non-aeration time whereas, TP removal increased with increasing non aeration time. However filamentous growth was observed with increasing non-aeration time. It can be concluded that intermittent aeration can be a good alternative for nutrient removal. By intermittently aerating the system, energy cost for aeration can also be cut-off.

Keywords — Activated Sludge Process, Intermittent aeration, Carboneous pollutant removal, Biological Nutrient Removal, Laboratory Scale Plant

I. INTRODUCTION

Carboneous compounds and nutrients are the major pollutants in wastewater. These are also the important parameters to assess the quality of water (Metcalf & Eddy, 2003b). These can be removed by physical, chemical and biological methods. Among the physiochemical processes, sedimentation, chemical precipitation, adsorption etc are the mostly used methods but these expensive and produce large amount of sludge which requires further treatment (Wei et al., 2003). Biological process is the best alternative at mostly preferred method due to low operational and maintenance cost (Aziz et al., 2019). In biological treatment process, carboneous pollutants is converted to biomass and gases like carbon dioxide, methane etc. (Low & Chase, 1999). Microorganisms, present in the system, will consume the carboneous pollutants present in the wastewater to multiply themselves (Henze et al., 2008). Carboneous pollutants requires oxygen to decompose, thereby reducing DO level in water which has negative impacts on aquatic life (Sawyer et al., 2003; Metcalf and Eddy, 2003). Similarly, nutrients (Nitrogen and Phosphorus) are the reasons for eutrophication (Camargo & Alonso, 2006). A lot of studies have been conducted on nutrient removal at both batch and continuous processes. Both of these processes have their own advantages and disadvantages. The selection of reactor depends upon the physical and chemical property of influent and effluent, flexibility, process control, volume of wastewater to be treated per unit time, nature of reaction (homogeneous/heterogeneous), reaction kinetics governing the treatment systems and local environmental conditions (Levenspiel, 1999; Krishna, 2013). Different economic analysis and environmental analysis have been done by many researchers to compare batch and continuous processes (Hessel et al., 2012; Jolliffe and Gerogiorgis, 2016; Schaber et al., 2016). In a batch process, the raw material is charged before the processing and the product is discharged after this period of processing. In a continuous process, the raw material and the product is charged and discharged simultaneously during the period of processing. These definitions can describe either a single unit operation or an integrated manufacturing process (Chen, 2017). Some of the advantages of batch reactors are good for small quantity, flexibility, ease of scaling up from lab, cheaper, good for slow reaction kinetics or conversion rate and ease of cleaning of reactor whereas that of continuous process is small reactor size, operational ease, less losses and good for large quantity (Karimi and Hasebe, 1995; Chen, 2017; Stricker and Béland, 2006). Activated sludge process was an accidental discovery by Edward Ardern and W.T. Lockett in 1913. The discover was actually a sequencing batch reactor where the wastewater was aerated for a certain time, the sludge was allowed to settle, supernatant liquid was decanted and the process was repeated. However, with difficulty in operation, it was later converted into continuous flow process. The concept of batch mode was again introduced. Conventional activated sludge process (ASP) was mostly designed to remove carboneous pollutants and not nitrogen. Most of the continuous ASP systems requires more footprint and are space oriented. The Sequencing Batch Reactor requires less footprint, controlled flow and energy input condition, time-oriented system (Irvine, Miller, & Bhamrah, 1979). The interest in sequencing batch treatment started again in early 1950s with Porges, when he used batch process to treat dairy wastewater. In 1970s Irvine and his team and Goronszy studied on suitability of SBR.

In late 1990s and early 2000s studies were conducted for removal of nutrients using SBR (Suman, Ahmad and Ahmad, 2017; Vigneswaran, Sundaravadivel and Chaudhary, 2007).

After the development of the activated sludge processes, several treatment configurations known as biological nutrient removal (BNR) systems have been designed under specific operation conditions for elimination of carbon, nitrogen, and phosphorus, according to the specific characteristics of the composition of the wastewater to be treated (Crittenden et al., 2012).

The developed systems to the biological nutrient removal are usually integrated by anaerobic, anoxic, and aerobic phases adjusted in series, whose number and arrangement can vary according to the configuration type to be used. In the anaerobic phases, the polyphosphate-accumulating organisms accumulate high energetic material as β-polyhydroxialkanoates (polyhydroxybutirate and polyhydroxyvalerate, mainly) inducing the polyphosphate (poly-P) release due to the absence of an external electron acceptor.

Subsequently, in the aerobic (or anoxic) phases, the polyphosphate-accumulating organisms use their energetic reserves and take up the phosphorus that is initially released in anaerobic phases to store it as intracellular polyphosphate (Henze et al., 2008).

On the other hand, the nitrogen elimination involves more complex mechanisms mediated by autotrophic and heterotrophic microorganisms, usually under aerobic and anoxic phases.

In the aerobic phase, autotrophic populations oxidize in two sequential steps the ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-) in the nitrification process. Then, in the anoxic phase, nitrite and nitrate are reduced to N_2 and escape to the atmosphere due to the denitrifying heterotrophic bacteria (Ekama, 2015).

Related to the removal of nitrogen, several researches have evidenced that the growth rate of the nitrifying bacteria is too low compared to other microbial populations in wastewater treatment processes (Metcalf and Eddy, 2003 ; Henze *et al.*, 2008).

Carbon sources play an important role in biological nitrogen and phosphorus removal. In biological nitrogen removal, organic carbon is required as an electron acceptor for denitrification. In biological phosphorus removal, organic carbon can be stored as an intracellular polymer in the phosphate accumulating organisms' cells to enable luxury phosphorus uptake (Peng et al., 2010; Mahendraker et al., 2005). Various semi continuous systems have been researched to treat the wastewater. Semi-continuous system can have the benefits of both batch and continuous processes.

The objective of this study is to make ASP a semi continuous process so that the benefits of both batch process and continuous process can be put together for better efficiency, less footprint, less cost and easier operation and with intermittent aeration, same reactor can act as anoxic and aerobic zone for removal of nitrogen from the wastewater. This study was carried out at Soil Water and Air Testing Laboratories, Kathmandu in 2018..

II. MATERIALS AND METHODS

A. Experimental setup

The synthetic wastewater was prepared using glucose (150 mg/L), sodium acetate (300 mg/L), peptone (15 mg/L), meat extract (15 mg/L), Ammonium choloride (140mg/L), Mono Potassium Phosphate (35 mg/L), Magnesium Sulphate Heptahydrate (30 mg/L) and Ferrous sulphate heptahydrate (5 mg/L) (Loosdrecht et al., 2016).

Sludge from Guheshwori WWTP was put into the reactor. A 6 inches PVC pipe was used to prepare the reactor. The outlet was fixed approximately 5 inches from bottom and the volume was measured which was 2.3 liters. An overhead stirrer and aquarium pump were used to aerate and keep the sludge suspended.

A 2-liter pet bottle was cut and was inverted so as to make a sedimentation tank to remove the suspended solid from effluent. Arduino was used to control the aeration and pumps. 2 peristaltic pumps were installed, one for the intermittent feeding of wastewater and one for recycling the sludge.

The feeding was done during the non-aeration phase only. The layout of the experimental setup is shown in Fig. 1. The experiment was conducted for HRT of 12 hours and SRT of 10 days. Operation cycle of 1 hour, 2 hour, 4 hours and 8 hours, with aeration-non aeration period of 25%-75%, 50%-50%, 75%-25% and 100%-0% were analyzed to determine the performance of pollutant removal.

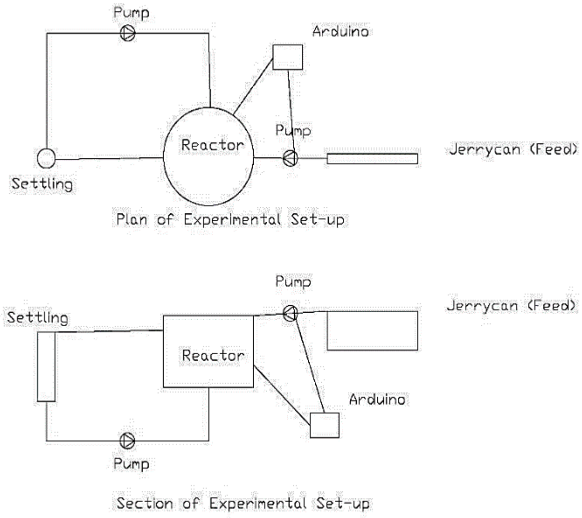

Fig. 1: Layout of experimental setup

B. Analytical methods

Samples were analyzed for influent and effluent in accordance with the Standard Methods (APHA, 2005). Analysis was done for Chemical Oxygen Demand (COD), Phosphorus and Total Kjeldahl Nitrogen (TKN). The analytical methodology adopted for the analysis of parameters are presented in Table 1.

Table 1 : Analytical methods adopted

S.N.	Parameter	Method Adopted
1	COD	5220 B. Closed reflux method, APHA 21st edition
2	Phosphorus	4500-P E. Ascorbic Acid Method, APHA 21st edition
3	TKN	4500 Total Kjeldahl Nitrogen, APHA 21st edition

C. Removal efficiency

Removal efficiency was calculated by dividing the difference between initial and final concentration by initial concentration and was expressed in percentage (%).

III. RESULTS AND DISCUSSION

A. COD removal

The COD removal has been presented in Table 2, Table 3, Table 4 and Table 5.

Table 2. COD removal at 1 hour cycle

S.N.	AT (min)	NAT (min)	CODi (mg/L)	CODe (mg/L)	Removal efficiency
1	60	0	482.2	63.8	86.75%
2	45	15	476.6	171.3	64.07%
3	30	30	470.2	248.7	47.08%
4	15	45	494.2	411.1	16.66%

Table 3. COD removal at 2 hour cycle

S.N.	AT (min)	NAT (min)	CODi (mg/L)	CODe (mg/L)	Removal efficiency
1	120	0	507.84	60.88	87.98%
2	90	30	512.4	145.1	71.65%
3	60	60	526.1	285.74	45.64%
4	30	90	510.92	433.1	15.15%

Table 4. COD removal at 4 hour cycle

S.N.	AT (min)	NAT (min)	CODi (mg/L)	CODe (mg/L)	Removal efficiency
1	240	0	506.94	62.28	87.67%
2	180	60	505.36	152.84	69.67%
3	120	120	516.54	222.38	56.89%
4	60	180	501.4	343.86	31.35%

Table 5. COD removal at 8 hour cycle

S.N.	AT (min)	NAT (min)	CODi (mg/L)	CODe (mg/L)	Removal efficiency
1	480	0	497.12	59.98	87.92%
2	360	120	504.72	140.36	72.17%
3	240	240	512.08	205.64	59.76%
4	120	360	504.8	314.05	37.78%

The COD removal is found to decrease with decreasing Aeration fraction for each cycles. Similarly, it can be observed that the efficiency increases if the cycle time increases. With increasing non-aeration time, the effective aeration time decreases leading to decrease in removal of COD from the wastewater.

B. Total Kjeldahl Nitrogen Removal

The TKN removal has been presented in *Table 6*,

Table 7,

Table 8 and

Table 9.

Table 6 Total Kjeldahl Nitrogen Removal at 1 hour cycle

S.N.	AT (min)	NAT (min)	TKNi (mg/L)	TKNe (mg/L)	Removal efficiency
1	60	0	36.6	3.5	90.32%
2	45	15	35.7	14.3	59.78%
3	30	30	37.2	21.2	42.75%
4	15	45	36.9	30.7	16.81%

Table 7 Total Kjeldahl Nitrogen Removal at 2 hour cycle

S.N.	AT (min)	NAT (min)	TKNi (mg/L)	TKNe (mg/L)	Removal efficiency
1	120	0	34.32	3.84	88.80%
2	90	30	34.14	8.52	74.96%
3	60	60	33.94	21.72	35.81%
4	30	90	34.98	28.34	18.41%

Table 8 Total Kjeldahl Nitrogen Removal at 4 hour cycle

S.N.	AT (min)	NAT (min)	TKNi (mg/L)	TKNe (mg/L)	Removal efficiency
1	240	0	35.12	3.5	89.94%
2	180	60	34.48	13.56	60.48%
3	120	120	33.14	17.7	46.43%
4	60	180	34.14	26.76	21.06%

Table 9. Total Kjeldahl Nitrogen Removal at 8 hour cycle

S.N.	AT (min)	NAT (min)	TKNi (mg/L)	TKNe (mg/L)	Removal efficiency
1	480	0	34.58	90.34%	87.92%
2	360	120	34.7	64.73%	72.17%
3	240	240	34.56	49.13%	59.76%
4	120	360	34.95	23.73%	37.78%

The TKN removal is found to decrease with decreasing Aeration fraction for each cycle. Similarly, it can be observed that the efficiency increases if the cycle time increases. With increasing non-aeration time, the effective aeration time decreases leading to decrease in removal of TKN from the wastewater.

C. Total Phosphorus Removal

The total phosphorus removal has been presented in *Table 10*,

Table 11,

Table 12 and *Table 13*.

Table 10 Total Phosphorus at 1 hour cycle

S.N.	AT (min)	NAT (min)	Pi (mg/L)	Pe (mg/L)	Removal efficiency
1	60	0	9.9	9.0	8.58%
2	45	15	9.5	8.6	9.75%
3	30	30	9.6	8.2	14.52%
4	15	45	9.5	8.3	12.03%

Table 11 Total Phosphorus at 2 hour cycle

S.N.	AT (min)	NAT (min)	Pi (mg/L)	Pe (mg/L)	Removal efficiency
1	120	0	9.5	8.54	10.05%
2	90	30	9.46	7.6	19.24%
3	60	60	9.34	7.32	21.48%
4	30	90	9.26	6.66	27.64%

Table 12 Total Phosphorus at 4 hour cycle

S.N.	AT (min)	NAT (min)	Pi (mg/L)	Pe (mg/L)	Removal efficiency
1	240	0	9.34	8.52	8.46%
2	180	60	10.06	7.6	24.39%
3	120	120	9.48	2.56	72.76%
4	60	180	9.1	1.72	81.05%

Table 13 Total Phosphorus at 8 hour cycle

S.N.	AT (min)	NAT (min)	Pi (mg/L)	Pe (mg/L)	Removal efficiency
1	480	0	9.58	8.6	10.20%
2	360	120	9.6	2.6	72.77%
3	240	240	9.52	1.54	83.68%
4	120	360	9.9	1.05	89.44%

It can be found that the removal increases with increasing cycle time and increasing non-aeration time. With increasing non-aeration time, the effective anaerobic condition increases. With the increasing non aeration time, and even with slightest of aerobic condition on aeration phase, the PAOs can accumulate the phosphorus.

IV. CONCLUSION

This study concludes that for the same HRT and SRT, the removal varies with change in aeration and non-aeration phase. COD, TKN and TP removal increases with increasing project cycle for same aeration fraction.

The reason could be the effective aeration and non-aeration time that aeration and non-aeration phase provide. Microorganism might need some time to adapt to the changing environment. This could be the reason that the cycle of 1 hour was found to be ineffective in nutrient removal.

Also another advantage of intermittent aeration is the decrease in energy cost of the system. With intermittent aeration, the cost of aeration can be cut down.

The study found filamentous growth in longer non-aeration time. Hence, when designing an intermittently aerated system, one should be careful that non-aeration time doesn't increase beyond 120 minutes.

Overall, intermittent aeration is found to be effective in removal of nutrients but the removal of COD decreases. Hence a detailed analysis needs to be done considering other cycle hours and aeration fraction.

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ABBREVIATIONS

CREEW	Center of Research for Environment, Energy and Water
COD	Chemical oxygen demand
HRT (Θ)	Hydraulic Retention time
L	Litre
mg	Milligram
mg/l	Milligrams/liter
MLSS	Mixed Liquor Suspended Solid
MLVSS (X)	Mixed Liquor Volatile Suspended Solid
obs.	Observations
PAOs	Phosphate Accumulating Organisms
SRT (Θ_c)	Solid Retention time, Mean Cell Residence Time
SWAT Lab	Soil Water and Air Testing Laboratories
TKN	Total Kjeldahl Nitrogen
TKNe	Effluent TKN concentration
TKNi	Influent TKN concentration
TP	Total Phosphorus
TPe	Effluent Total Phosphorus
TPi	Influent Total Phosphorus
WWTP	Wastewater Treatment Plant
%	Percentage

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