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Studying the performance and kinetic values for pollutant removal using lab scale plant

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Abstract

The present study aimed at determining performance and pollutant removal kinetics in the treatment of wastewater using a laboratory-scale continuous flow stirred tank reactor (CFSTR) based on activated sludge process (ASP). The waste activated sludge from the Guheshwori Wastewater Treatment Plant (WWTP) is used as a start-up seed sludge. The CFSTR is operated at varying solid retention time (SRT) of 1, 2, 3, 5, 7.5 and 10 days using synthetic wastewater prepared daily as an influent. Chemical Oxygen Demand (COD) and Total Kjeldahl Nitrogen (TKN) of the influent, effluent and Mixed Liquor Volatile Suspended Solids (MLVSS) of aeration tank are analyzed at various SRT to determine the respective kinetic coefficients. The COD and TKN removal increased with increasing SRT. The kinetic coefficients; maximum substrate utilization rate (k), the half velocity constant (K_s), cell yield coefficient (Y) and decay coefficient (k_d) have been found to be 1.61 g COD/g VSS · day, 87.22 mg/L, 0.50 g Volatile Suspended Solid (VSS)/g COD and 0.07 day^{-1} respectively for synthetic wastewater. Similarly, k, Ks, Y and kd for the treatment of wastewater from Guheswori WWTP have been observed to be 1.86 g COD/g VSS.day, 107.77 mg/L, 0.32 g VSS/g COD and 0.04 day^{-1}.

Keywords: Activated sludge process; solid retention time; wastewater treatment plant; kinetic coefficient; laboratory scale plant

1. Introduction

Water bodies, in Hindu mythology, is considered as a form of god and people perform various rituals at these bodies. However, with increasing population and settlement near these water bodies, these are being polluted and non-potable [1, 2]. Government of Nepal in support of various other organizations are now planning and constructing many wastewater treatment plants. There are many physiochemical processes for the removal of carboneous and nutrients from the wastewater. Some of them are sedimentation, chemical precipitation, adsorption etc but these methods are mostly expensive and produce huge quantity of side products (sludge) which again needs further processing [3]. Hence the biological process is the best alternative due to low operational cost and environmental benefits [4]. In biologically treated wastewater treatment plants, organic contaminants is converted to sludge (biomass) and gases like carbon dioxide, methane etc. [5]. Microorganisms consume the organic matters present in the wastewater and increase their numbers [6].

Government of Nepal also proposed 5 biological wastewater treatment plants for the improvement of Bagmati River Basin. Currently, Guheshwori Wastewater Treatment Plant (WWTP) is the only functional wastewater treatment plant among the centralized wastewater treatment plants [1, 7, 8, 9]. The Kathmandu Valley Wastewater Management Project of Project Implementation Directorate of Kathmandu Valley Water Supply Limited is planning to treat 90.5 MLD and 382.1 MLD of wastewater by 2020 and 2030 respectively of Kathmandu valley. The activated sludge process is the most commonly used biological system in the world as it is a robust technology but the operating cost is slightly high [10-12]. Most of the planned treatment plants are Activated Sludge Process [13], some are Sequencing Batch Reactor (SBR) and Constructed Wetlands. Most of them are still under design phase. With limited data to design the existing treatment plants, most of the parameters were adopted using similar treatment plants in other countries. However the kinetic parameter depends upon the climatic condition, microorganisms and technology involved and wastewater characteristics [14-16]. It is very common to design the wastewater treatment using simplified hydraulic related parameters only but this is not adequate for efficient operation and performance [17]. The composition of municipal wastewater is very complex and vary with a lot of physical, social, biological and other conditions [14], [18], [19]. Kinetic approach should be used rather than depending on hydraulic parameter only. Carbonaceous pollutant is an important parameter to assess the quality of water as it requires oxygen to decompose itself thereby depleting the DO level in water which has negative impacts on aquatic life [14], [19]. Similarly, nutrients (Nitrogen and Phosphorus) are the reasons for eutrophication. In most of the cases, even Nitrogen content only can contribute in production of algae, hence removing nitrogen only can help in reducing the eutrophication process [20]. Nitrate and ammonium are the major nitrogen sources for phytoplankton and plant growth. However, with lower energetic costs associated, plants and phytoplankton prefer ammonium to nitrate during assimilation. The productivity is higher in presence of ammonium concentrations rather than nitrate concentration [21]. Also the aquatic toxicity is higher for ammonia than nitrate [20], [22]. For nitrogen removal, there are two stages: nitrification and denitrification [23]. Nitrification is a process of nitrogen compound oxidation (effectively, loss of electrons from the nitrogen atom to the oxygen atoms), and is catalyzed step-wise by a series of enzymes

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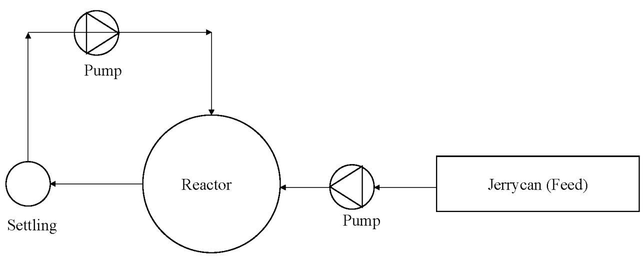

Figure 1: Layout of experimental setup.

using Eq. 1 and Eq. 2.

$$2NH_4^+ + 3O_2 \rightarrow 2\,NO_2^- + 2H_2O \text{ (Nitrosomonas)} \quad (1)$$
$$2\,NO_2^- + O_2 \rightarrow 2NO_3^- \text{ (Nitrobacter)} \quad (2)$$

Denitrification is a microbially facilitated process where nitrate ($NO3^-$) is reduced and ultimately produces molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products using Eq. 3.

$$2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + H_2O \text{ (Denitrifiers)} \quad (3)$$

For the removal, a separate chamber or facility is required with carbon source for the growth of denitrifiers which are heterotrophs. Nitrification can be done in the same chamber that is used for carboneous pollutant removal. Hence, most of the wastewater treatment plants that are designed on regulation that doesn't have a criterion to remove nitrate, don't consider nutrient removal as an option. This study was conducted to study the performance for COD and TKN removal for varying Solid Retention time (SRT) and kinetic parameters for designing wastewater treatment plants in Kathmandu and similar regions. This study was carried out at Soil Water and Air Testing Laboratories, Kathmandu in 2018.

2. Materials and methods

2.1. Experimental setup

The synthetic wastewater was prepared with the concentration of glucose of 150 mg/L, sodium acetate of 300 mg/L, peptone of 15 mg/L, meat extract of 15 mg/L, ammonium choloride of 140 mg/L, mono potassium phosphate of 35 mg/L, magnesium sulphate heptahydrate of 30 mg/L and ferrous sulphate heptahydrate of 5 mg/L [24]. The wastewater quality was found to be; COD of 486 mg/L, ammonia N of 32 mg/L, total nitrogen of 63 mg/L and total phosphorus of 9.5 mg/L. Sludge from Guheshwori WWTP was put into the reactor. Similarly, wastewater from Guheshwori WWTP was collected in jerrycan of 10 litres and was used for the study.

A 6-inch PVC pipe with a cap was used to construct the reactor. The outlet was fixed at approximately 5 inches from bottom and the volume was measured which was 2.3 liters. An overhead stirrer and aquarium pump was 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. 2 peristaltic pumps were installed, one for the continuous feeding of wastewater and one for recycling the sludge. The recycling was controlled by Arduino so as to maintain the SRT. The layout of the experimental setup is shown in Fig. 1.

2.2. Analytical methods

Samples were analyzed for influent and effluent in accordance with the Standard Methods [25]. Analysis was done for mixed liquor volatile suspended solids (MLVSS), Total Kjeldahl Nitrogen (TKN) and chemical oxygen demand (COD). 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	MLVSS	*2540 E. APHA* 21st edition
2	COD	5220 B. Closed reflux method, APHA 21st edition
3	TKN	4500 Total Kjeldahl Nitrogen, APHA 21st edition

Table 2: Performance of COD removal for synthetic wastewater.

SRT (d)	CODin (mg/L)	CODe (mg/L)	Removal Efficiency
10	490.00 ±9.16	33.90±0.72	93.08±0.13%
7.5	481.20±4.11	42.04±7.48	91.26±1.51%
5	494.36±0.67	57.92±5.23	88.28±1.06%
3	475.96±0.65	93.22±3.82	80.41±0.08%
2	455.62±2.97	166.28±4.99	63.50±1.21%
1	519.76±3.65	248.50±6.63	52.19±1.33%

2.3. Removal efficiency

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

2.4. Study of kinetics

Kinetic parameters were determined using the same method as used in previous studies by [17], [26], [27].

$$\frac{\overline{X} \cdot \theta}{S_o - S_e} = \frac{K_s}{k} \cdot \frac{1}{S_e} + \frac{1}{k} \quad (4)$$

Where, X: MLVSS, θ: hydraulic rentention time or HRT; S_o: COD concentration in the influent, S: COD concentration in the effluent, k: maximum substrate utilization rate; K_s: the half velocity constant

Now plotting $\frac{\overline{X} \cdot \theta}{S_o - S_e}$ and $\frac{1}{S_e}$ from equation (4), we get the value of $\frac{K_s}{k}$ and $\frac{1}{k}$, from which the value of Ks and k can be determined.

$$\frac{1}{\theta_c} = Y \frac{S_o - S}{X \cdot \theta} - k_d \quad (5)$$

Where, Y: cell yield coefficient, θ_c: Solid Retention Time or SRT and k_d: decay coefficient or endogenous respiration.

From equation (5), yield and decay coefficient can be calculated.

3. Results and discussion

3.1. Performance of reactor on synthetic wastewater

The synthetic wastewater was used as feed with varying SRT ranging from 10 days to 1 day.

The plant was operated without analysis for number of days equivalent to SRT for adaptation of microorganism. Based on the analyzed data, the removal efficiency increased from 52.19% to 93.08% with increasing SRT. Similarly, Ammonia removal was significant only after SRT was above 5 days. The details of removal performance is given in Table 2 and Table 3.

Based on ANOVA test, p-value is very low, hence it can be concluded that the removal efficiency for both COD and TKN changes with SRT.

3.2. Performance of reactor on Guheshwori wastewater

The raw wastewater was collected from Guheshwori WWTP and was used as feed with varying SRT ranging from 10 days to 1 day. Based on the analyzed data, the removal efficiency increased from

Table 3: Performance of TKN removal for synthetic wastewater.

SRT (d)	TKNi (mg/L)	TKNe (mg/L)	Removal efficiency
10	33.1±2.74	3.48±0.28	89.48±0.95%
7.5	31.4±1.84	3.74±0.36	88.07±1.33%
5	33.6±3.45	8.96±1.56	73.30±3.23%
3	34.9±1.43	26.64±1.67	23.62±6.08%
2	32.6±3.09	28.78±3.32	11.77±13.54%
1	32.7±1.95	32.20±2.10	1.59±3.99%

Table 4: Performance of COD removal for wastewater from Guheshwori WWTP.

SRT (d)	CODin (mg/L)	CODe (mg/L)	Removal Efficiency
10	808.78±12.83	68.94±6.03	91.48±0.63%
7.5	782.60±8.80	82.54±2.19	89.45±0.27%
5	769.44±10.95	109.46±5.96	85.77±0.59%
3	784.60±16.58	199.78±4.22	74.54±0.13%
2	800.58±6.24	329.44±3.69	58.85±0.38%
1	803.92±4.01	367.88±3.02	54.24±0.17%

54.24% to 91.48% with increasing SRT. The NH4-N removal was effective only after the SRT was above 5 days. The details of removal performance are given in Table 4 and Table 5.

Based on ANOVA test, p-value is very low, hence it can be concluded that the removal efficiency for both COD and TKN changes with SRT.

The removal of COD and TKN increased with increase in SRT in both wastewater samples. The TKN removal increased with increasing SRT. This is because at low SRT, nitrifiers growth was limited which increased with increase in SRT as they cannot compete with heterotrophs at less SRT [28]. There is no justification for COD removal but the reason could be increasing MLSS value with increasing SRT. With more microorganisms, the removal also increases.

3.3. Kinetic study

Table 6 and Table 7 was used to plot the graph Fig. 2, Fig. 3, Fig. 4 and Fig. 5. Based on these graphs, values of K, K_s, Y and k_d were determined.

3.3.1. Kinetic study on synthetic wastewater

The values of K, K_s, Y, k_d and U_{max} were found to be 1.61 d^{-1}, 87.22 mg/L, 0.50 (kg VSS /kg COD), 0.07 d^{-1} and 0.81 d^{-1} respectively.

3.3.2. Kinetic study on wastewater of Guheshwori

Based on the experiment conducted, the yield of microorganism using Guheshwori WWTP was found to be 0.32 (kg VSS /kg COD). The kinetic values k_d, K and K_s were found to be 0.05 d^{-1}, 1.61 g COD/g VSS·d, 1.86 g COD/g VSS·d and 107.77 mg/L respectively. All

Table 5: Performance of TKN removal for wastewater from Guheshwori WWTP.

SRT (d)	TKNi (mg/L)	TKNe (mg/L)	Removal Efficiency
10	75.26±3.35	10.70±1.23	85.78±1.23%
7.5	75.00±4.36	13.68±1.82	81.76±2.41%
5	73.44±2.59	19.28±6.33	73.75±7.87%
3	71.92±4.05	59.74±7.59	17.02±7.62%
2	74.20±4.47	62.16±4.84	16.23±6.01%
1	75.96±3.78	70.72±3.38	6.90±3.04%

Table 6: Values obtained from experiment to determine kinetic values for synthetic wastewater

SRT	Xvss	1/SRT	$\frac{(So-S)}{(\text{HRT}\cdot X)}$	$\frac{(X\cdot HRT)}{(S_o-S)}$	$1/S$
10	1985.4	0.1	0.46	2.18	0.0294
7.5	1667.8	0.13	0.52	1.91	0.0238
5	1245.6	0.2	0.7	1.43	0.0173
3	1135	0.33	0.68	1.48	0.0107
2	687	0.5	0.84	1.19	0.006
1	247.2	1	2.21	0.45	0.004

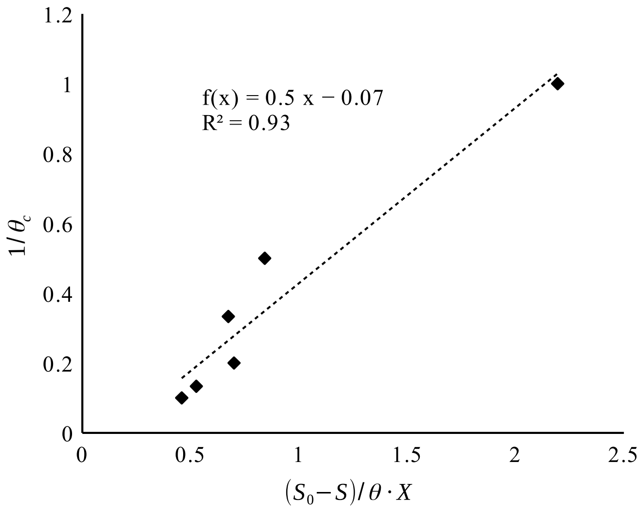

Figure 2: Evaluation of Y and k_d for synthetic wastewater using performance data.

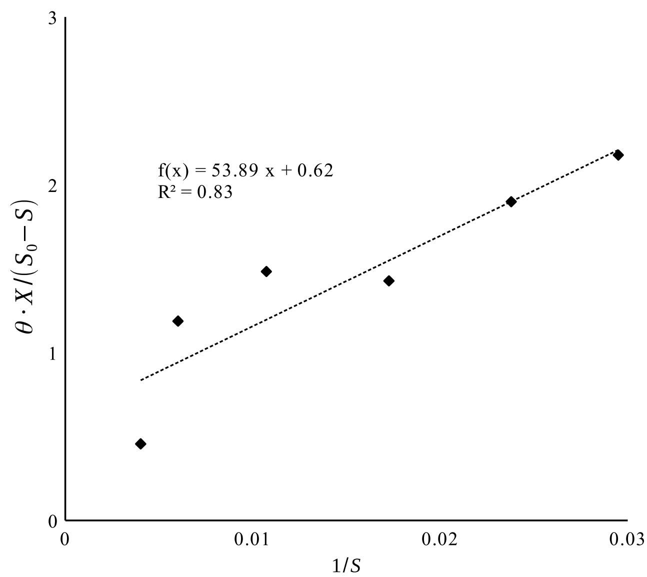

Figure 3: Evaluation of K and K_s for synthetic wastewater using performance data.

Table 7: Values obtained from experiment to determine kinetic values for wastewater from Guheshwori WWTP

SRT	Xvss	1/SRT	$\frac{(S_o-S)}{(\text{HRT}\cdot X)}$	$\frac{(X\cdot HRT)}{(S_o-S)}$	$1/S$
10	1877.4	0.1	0.79	1.27	0.0145
7.5	1801.8	0.13	0.78	1.29	0.0121
5	1421.8	0.2	0.93	1.08	0.0091
3	1317	0.33	0.89	1.13	0.005
2	801.4	0.5	1.18	0.85	0.003
1	264.4	1	3.3	0.3	0.0027

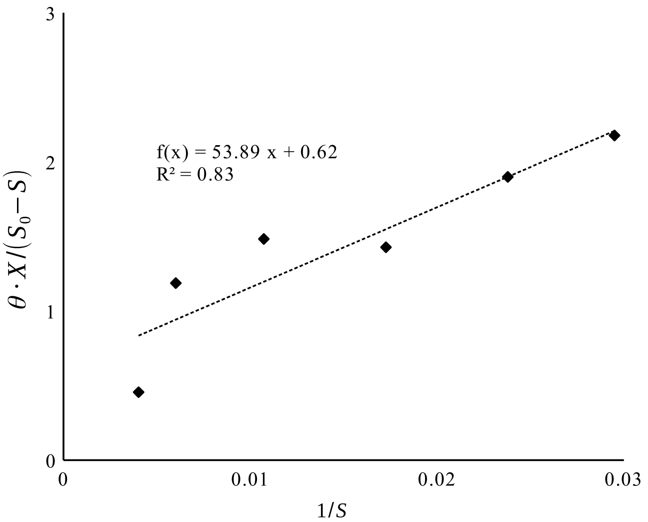

Figure 4: Evaluation of Y and k_d for wastewater from Guheshwori WWTP using performance data.

the kinetic values K_s, Y and k_d are in the standard range [14], [29]. The value of K plays a significant role in required volume of the reactor. This value can be used for designing other biological treatment systems too including aerated lagoon or stabilization pond [17]. The obtained value is toward the lower range [14]. Lower value of k_d means larger net sludge volume production from the treatment plant as the decay of microorganism is low.

All the kinetic values k (d^{-1}), K_s, Y and k_d are in the range [14], [29]. The kinetic parameter at Guheshwori WWTP for yield coefficient (Y), decay coefficient (k_d), maximum specific growth rate and saturation constant (K_s) for GWWTP was reported to be 0.18 g VSS /g COD, 0.05 d^{-1}, 5.26 g COD/g VSS.d and 27.26 mg/L [27], however, the same kinetic parameters for the wastewater obtained from same WWTP is different from this study. This result suggests that the Guheshwori WWTP is not functioning properly and there is limited biological activity at Guheshwori WWTP. The kinetic parameter of wastewater from Guheshwori WWTP and synthetic wastewater also varied in our experiment. This suggests that the Guheshwori WWTP might have toxicity that is avoiding the yield and growth rate of the microorganisms.

Oxidation ditch is supposed to have higher endogenous decay value than completely mixed activated sludge process. Higher value indicates larger sludge volumes from biological treatment [14], [17]. k_d value of Guheshwori WWTP was very low compared to the experimental values of both wastewaters. This might be because the SRT of Guheshwori WWTP was lower than design value [27].

4. Conclusion

With increasing SRT, the performance of COD and TKN removal increases. The mixed liquor suspended solid (MLSS) value is lower

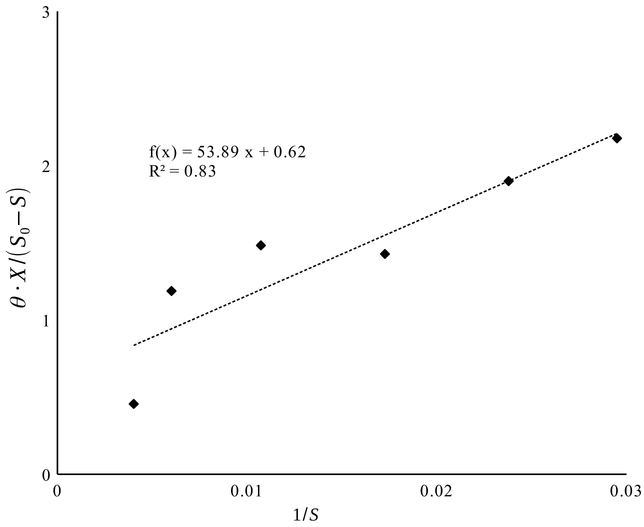

Figure 5: Evaluation of k and K_s for wastewater from Guheshwori WWTP using performance data.

at lower SRT which increases the Food to Microorganism ratio (F/M) thereby limiting the removal. The removal of TKN is very less below the SRT of 5 days. At lower SRTs, nitrifiers cannot compete with heterotrophs which reduces the TKN removal. The yields at Guheshwori WWTP from previous study and experimental value of wastewater from Guheshwori WWTP were lower than the experimental value of synthetic wastewater which suggests the possibility of toxicity in incoming wastewater at Guheshwori WWTP. The kinetic values obtained from this experiment can be used to design wastewater treatment plants in Nepal and in regions with similar environmental conditions. This study is limited to removal of TKN. Similar study can be conducted considering the removal of nitrate and phosphorus too.

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