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Integrated Submerged Media Extended Aeration Activated Sludge (ISmEAAS) Reactor Start-Up and Biomass Acclimatization

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Abstract: The present study elucidates the start-up and biomass acclimatization of the existing bench-scale extended aeration activated sludge (EAAS) reactor. Furthermore, the feasibility of upgrading the existing reactor into an integrated submerged media system was also investigated. In this study, two identical bench-scale EAAS reactors were set up for biomass acclimatization in continuous flow mode for 45 days. Both reactors achieved a steady state for COD removal on the 29th and 31st days, with a removal efficiency of approximately 90%. The TSS removal attained stability on the 37th and 39th days, with a removal efficiency of approximately 50%. Both reactors achieved steady state for nutrient removal later to organic removal. The ammonia concentration achieved a steady state on the 39th day. Likewise, total phosphorus concentration became stable more or less at the same period. The removal efficiency of nutrients was found to be approximately 50%, which is not par with organic. Thus, upgrading the existing treatment facility is a scope to enhance treatment efficiency to achieve stringent wastewater discharge limits.

Keywords: integrated wastewater treatment system, EAAS reactor, acclimatization, medium strength wastewater, continuous flow mode.

集成浸没介质扩展曝气活性污泥 (伊斯马斯) 反应器启动和生物质驯化

摘要：本研究阐明了现有实验室规模扩展曝气活性污泥 (EAAS) 反应器的启动和生物量驯化。此外，还研究了将现有反应器升级为集成浸没介质系统的可行性。在这项研究中，建立了两个相同的实验室规模 EAAS 反应器，以连续流动模式适应生物质 45 天。两个反应器在第 29 天和第 31 天实现了货到付款去除的稳定状态，去除效率约为 90%。TSS 去除在第 37 天和第 39 天达到稳定，去除效率约为 50%。两个反应器均达到稳定状态，以便在有机物去除之后去除营养物。氨浓度在第 39 天达到稳定状态。同样，总磷浓度在同一时期或多或少变得稳定。发现营养物质的去除效率约为 50%，这与有机物不相称。因此，升级现有处理设施是提高处理效率以达到严格的废水排放限制的范围。

关键词：综合污水处理系统, EAAS 反应堆, 适应, 中等浓度废水, 连续流动模式。

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1. Introduction

Wastewater treatment has always been a challenge due to the increasing scarcity of potable water [1, 2]. The discharging of wastewater with high nutrient concentration can lead to the problem of eutrophication in receiving water bodies [3, 4]. The stringent policies of water pollution regulatory bodies are a compelling challenge to improve the treatment capacity of existing conventional wastewater treatment facilities. Thus, an integrated biofilm reactor with conventional activated sludge (CAS) system is a suitable solution to achieve the stringent discharge limits [5-7]. However, many studies were reported in the field of upgrading existing CAS systems into integrated biofilm reactors through minor modification or retrofitting [8-10].

The extended aeration activated sludge (EAAS) system was the most desirable modified activated sludge system, which offers low BOD effluent and less waste activated sludge. However, a few drawbacks of mixing in the large reactor and high-energy requirement still exist in EAAS systems with small-scale facilities [11-14]. Integration of EAAS system with submerged biofilm carriers can offer advantages, to name a few 1) increases the removal rate of organics, 2) more advanced wastewater treatments can be endorsed by longer SRT, 3) enhances the nutrient removal, 4) reduces the footprint [15-20]. The start-up of wastewater treatment plants plays an important role in successful operation. However, inapt starting can lead to ineffective treatment efficiency [21-23].

The present study targeted the start-up of the bench-scale EAAS system as an integrated submerged media biofilm system by installing a commercially available basket fed with medium strength wastewater, which has never been studied before as per the authors' extensive literature knowledge. Furthermore, we observed the removal efficiency of the existing EAAS reactor. Moreover, the feasibility of upgrading the existing EAAS reactor into an Integrated submerged media extended aeration activated sludge (ISmEAAS) was also studied.

2. Materials and Method

2.1. Experimental Setup

The bench-scale extended aeration activated sludge (EAAS) reactor of 5 mm thick Perspex was fabricated. The total working volume of the reactor is about 10 L. The whole dimension of the reactor is given in Table 1 [24]. A commercially available basket of appropriate size is hanged for submerging into the aeration zone of the EAAS reactor to make it integrated submerged media extended aeration activated sludge (ISmEAAS). Two identical EAAS reactors were set up; 1) Reactor A as a control, 2) Reactor B as an ISmEAAS. The air supplied through air pump from Hailea® (Model HAP-100) of a maximum output of 100 L/min. The influent wastewater pumped through medium flowrate peristaltic pump from Longerpump® (Model: BT300-2J). Initially, the flow rate of the pump was adjusted to 5 L/d. The overall capacity of the installed influent tank (Saint Gobain) was 55 L. The dissolved oxygen (DO) was monitored regularly by DO meter (model YSI 5100) while maintained between 4.5 to 5 mg/L. Fig. 1 illustrates the schematic diagram of the experimental setup.

Table 1 Dimension of EAAS reactor [24]

Reactor	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)
Complete dimension	36.5	16.0	24.0	14100
Aeration Zone	30.0	16.0	24.0	11500
Clarifier	6.5	16.0	24.0	2500
Free Board	3 (cm)			
Flowrate	0.01 (m^3/d)			

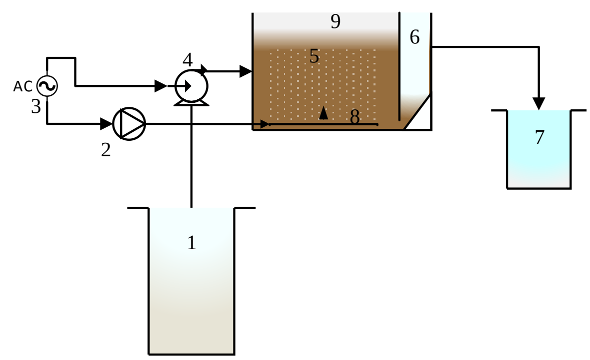

Fig. 1 Schematic diagram of the experimental setup: (1) Influent tank; (2) Centrifugal pump; (3) AC supply; (4) Peristaltic pump; (5) Aeration zone; (6) Clarifier; (7) Effluent tank; (8) Air diffuser; (9) EAAS reactor

2.2. Synthetic Wastewater

Reactors were fed with medium-strength synthetic wastewater. The synthetic wastewater was prepared using Purina Alpo high protein Puppy food, available commercially. Before using, the Puppy food was ground in the blender for 10 minutes [25]. The ammonium chloride salt is added to induce nitrogen content. The BOD nutrient pillow is used as a phosphate buffer with sodium bicarbonate to maintain pH and ensure adequate alkalinity within the range recommended for nitrification. The constituents of medium strength wastewater consist of 650 mg/L of Puppy food; 105 mg/L of Ammonium chloride; 280 mg/L of sodium bicarbonate; 0.15 mL/L of BOD nutrient pillow. The calculated C: N: P ratio of the synthetic wastewater was found to be 100: 6: 2. The ratios have met the minimum requirement of 100: 5: 1 for aerobic treatment of domestic wastewater to produce adequate nutrients for biomass.

2.3. Seeding of Reactor

The biomass used as inoculum in the reactor was collected from return activated sludge (RAS) pipe at the sewage treatment plant (STP) of UTP. The volume of sludge was determined by selecting the appropriate sludge age ranging between 15 to 25 days [24]. The desired steady-state period was preferred when the percentage of the standard deviations on the average efficiencies of TSS, COD, NH_3–N, NO_3^-–N, and Total phosphorus, MLSS, and MLVSS and SVI was less than 10% [24, 26, 27].

2.4. Analytical Methods

The influent wastewater sample characteristics were analyzed before feeding into the reactor. The effluent characteristics were determined after 48 hours—all samples were measured in triplicate.

2.4.1. Total Suspended Solids

Wastewater contains solids in various ranges. Suspended solids are one of the constituents in wastewater, which is considered a significant contaminant [28]. The total suspended solids (TSS), measured for influent and effluent by using standard procedure. Initially, filter paper with 47mm pore size (Whatman® Grade 4, Merck, Sigma Aldrich) was weighed with digital analytical balance (Mettler Toledo, ME 104), then placed on vacuum filtration apparatus. Gently, 100 mL of wastewater sample was poured into the apparatus for filtration. After filtration, the filter paper dried in the oven for 1 hour at 105°C. Filter papers desiccated for 10 minutes before final weighing. The following equation 1, used to determine the concentration of TSS in mg/L.

$$TSS = (W_f - W_i) \times 1000/V_s \tag{1}$$

where:
TSS - Total Suspended Solids (mg/L);
W_f - Final weight of filter paper after filtration and oven drying at 105°C (g);
W_i - Initial weight of filter paper before filtration (g);
V_s - Volume of sample (L).

2.4.2. Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS)

The procedure from standard methods was adopted to measure MLSS and MLVSS concentration [28]. The glass microfiber filter (Whatman® Grade GF/A, 47mm pore size from Merck, Sigma Aldrich) was weighed with digital analytical balance (Mettler Toledo, ME 104). The mixed liquor sample of 10 mL, collected from the aeration zone of the reactor, was diluted in a 1:10 ratio. The glass microfiber filter was gently placed on the vacuum filtration apparatus, 25 mL of diluted, mixed liquor sample was poured on the filter for solids measurement. After filtration, the glass microfiber filter dried in the oven for 1 hour at 105°C. The microfiber filter desiccated for 10 minutes to cool down to room temperature before weighing. The solid that remained was MLSS. Moreover, filters with MLSS residue were ignited in a muffle furnace (Protherm PLF 110/45) at 550°C for 15 minutes. The loss in weight of the filter after ignition represents volatile suspended solids. The following equation 2 and 3, used to determine the concentration of MLSS and MLVSS in mg/L, respectively.

$$MLSS = \frac{(B-A)}{V_{ML}} \times D_f \tag{2}$$

$$MLVSS = \frac{(B-C)}{V_{ML}} \times D_f \tag{3}$$

where:
A - Initial weight of glass microfiber filter;
B - Weight of filter after oven drying at 105°C (mg);
C - Weight of filter after ignition of volatile suspended solids at 550°C (mg);
V_{ML} - Volume of diluted, mixed liquor samples (L);
D_f - Dilution factor.

2.4.3. Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is equivalent to the organic matter in wastewater samples that can be chemically oxidized using dichromate in acid solution [28]. The procedure adopted for COD measurement was (HACH Method 8000). The COD digestion vial HR-20 was used. The COD vials were pipetted with 2 mL of wastewater samples, while 2 mL of distilled water pipetted for the blank sample preparation. HACH spectrophotometer DR 3900, used to determine the calorimetric reading.

2.4.4. Ammonia-Nitrogen (NH_3–N)

The adopted procedure for Ammonia nitrogen (NH3-N) measurement was the Nessler Method (HACH Method 8083) [28]. Influent and effluent samples were collected and diluted in a 1:10 ratio. A 25 mL of sample was used. The blank was prepared using distilled water. Three drops of mineral stabilizer were added for complexing hardness in the sample, while three drops of dispersing agent, polyvinyl alcohol, were added for color formation in the reaction of Nessler reagent with ammonium ions. Moreover, 1 mL of Nessler reagent was also added and mixed. After leaving samples for one minute for reaction, a yellow color formed proportional to the ammonia concentration. A 10 mL sample was transferred into a 20 mL sample cell cuvette for calorimetric reading using HACH spectrophotometer DR 3900.

2.4.5. Nitrate-Nitrogen (NO_3^-–N)

The procedure adopted for Nitrate-nitrogen (NO_3^-–N) measurement was the cadmium reduction method (HACH 8039 using HACH powder pillow (HACH, 2017) [28]. The reduction of nitrate to nitrite ion takes place by Cadmium metal under an acidic medium with sulfanilic acid, which forms a diazonium salt intermediate. Thus, by coupling with gentisic acid, an amber-colored solution formed. The recommended amount of the wastewater sample was poured into a 25 mL sample cell cuvette. The reagent power pillow (NitraVer 5) was added and shaken vigorously for one minute and then allowed to react for 5 minutes. Meanwhile, blank prepared by pouring 10 mL of wastewater sample without NitraVer5 powder. The reading was recorded by using HACH Spectrophotometer DR3900.

2.4.6. Total Phosphorus

The procedure adopted for Total phosphorus (TP) measurement was the acid persulphate digestion method (HACH 8190) [28]. The influent and effluent samples were collected diluted in a 1:5 ratio. In the total phosphorus test vial, 5 mL of diluted sample was added with potassium persulfate powder pillow. The vial was placed into preheated digester block at 150°C for 30 minutes. After heating, vial cooled to room temperature, 2 mL of 1.54 N sodium hydroxide standard solutions added. The vial was cleaned externally, placed into a HACH spectrophotometer (DR3900) to set zero. The reagent powder pillow (PhosVer3) was added and mixed thoroughly for about 20 to 30 seconds. The reading was then recorded.

2.4.7. Sludge Volume Index (SVI)

The fundamental definition of Sludge volume index (SVI) is the volume of 1 g of sludge observed after settling for 30 minutes. The standard method procedure was followed to determine SVI [28]. The mixed-liquor sample was poured in a 1 Liter measuring cylinder, allowed settling for 30 minutes. The settled volume (SV) was recorded with the corresponding sample MLSS concentration. The following formula is applied to calculate the numerical value of SVI [25]:

$$SVI = (SV \times 1000)/MLSS \quad (4)$$

where:
SVI - sludge volume index (mL/g);
SV - settled volume of sludge after 30 minutes (mL/L);
MLSS - mixed liquor suspended solids (mg/L).

3. Results and Discussion

3.1. Total Chemical Oxygen Demand (TCOD)

The TCOD concentration of medium-strength synthetic wastewater was measured before feeding the reactor. The average influent COD was 500.7 mg/L. The effluent concentration was measured after 48 hours. Initially, the fluctuation was observed. Reactor A attained a steady state after the 29th day when very minute fluctuation was observed in effluent TCOD concentration. The average removal efficiency was 86.2%. Moreover, reactor B achieved a steady state of TCOD concentration after the 31st day with an average removal efficiency of 88.9 %. The influent and effluent TCOD concentrations with a removal efficiency of reactor A and reactor B are schematically shown in Fig. 2 (a) and (b), respectively.

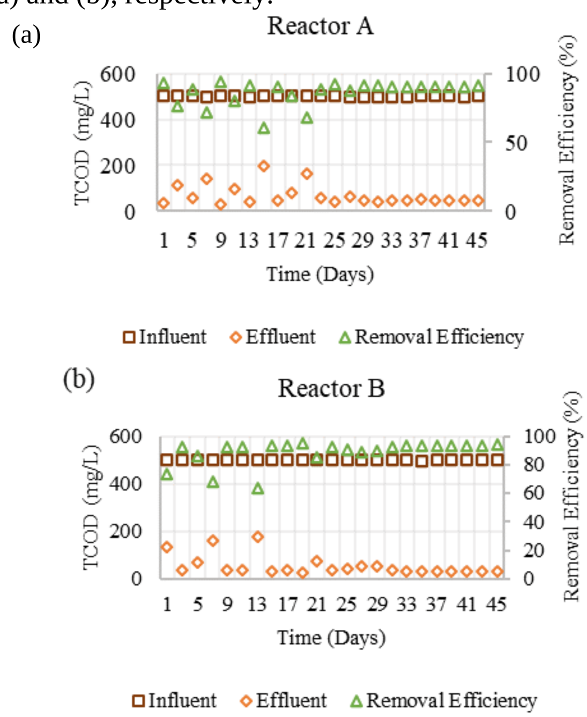

Fig. 2 TCOD concentration of influent and effluent with removal efficiency: (a) Reactor A, (b) Reactor B

3.2. Total Suspended Solids (TSS)

The influent was mix vigorously to make the synthetic wastewater homogeneous before feeding into reactors. The average TSS concentration of influent was

59.6 %. Reactor A and reactor B achieved a steady state after the 37th and 39th days, respectively. The removal efficiency of reactor A and reactor B was 45.3% and 51.2%, respectively. The influent and effluent TSS concentrations with removal efficiency of reactor A and reactor B are plotted in Fig. 3 (a) and (b), respectively.

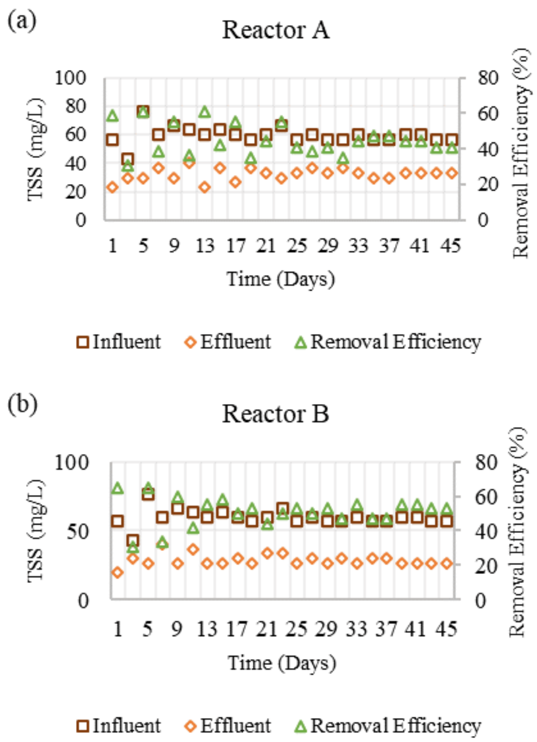

Fig. 3 TSS concentration of influent and effluent with removal efficiency: (a) Reactor A, (b) Reactor B

3.3. Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS)

The MLSS and MLVSS of both reactors were monitored on every alternate day. The biomass of both reactors was observed to be growing gradually. The biomass growth reached a steady state at the 41st for reactor A and Reactor B. MLSS concentration for reactor A and reactor B at a steady state were 1466.7 mg/L and 1600 mg/L, respectively. The MLSS and MLVSS concentrations of both reactors are illustrated in Fig. 4 (a) and (b), respectively.

3.4. Total Phosphorus (TP)

The average influent TP concentration was 10 mg/L. The steady state condition for both reactors was achieved on the 41st day. The average removal efficiency of reactors A and B was 47.51% and 40.02%, respectively. Figures 5 (a) and (b) illustrate the influent and effluent TP concentration with removal efficiency of reactor A and B, respectively.

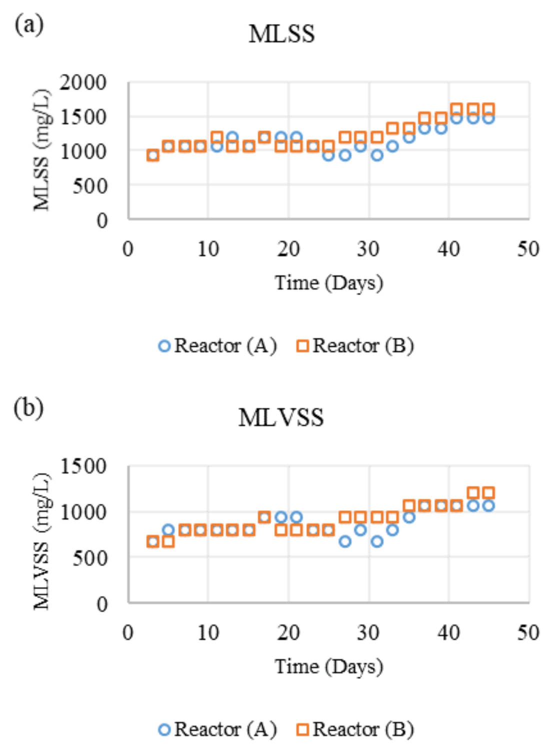

Fig. 4 The biomass concentration of reactors A and B: (a) MLSS, (b) MLVSS

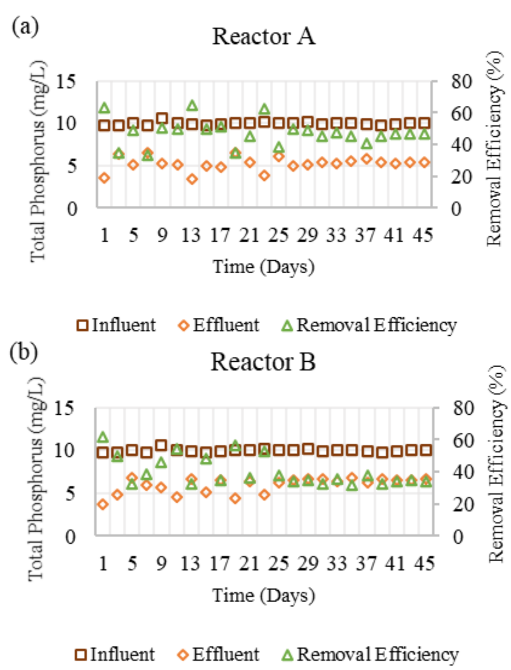

Fig. 5 TP concentration of influent and effluent with removal efficiency: (a) Reactor A, (b) Reactor B

3.5. Ammonia-Nitrogen (NH_3–N)

The average influent NH_3–N concentration of 20 mg/L was maintained by adding an appropriate quantity of ammonium salt. The steady states of reactor A and reactor B were achieved after 39th and 37th days, respectively. The average removal efficiency of reactor A and reactor B is 63.06% and 66.86%, respectively.

Figures 6 (a) and (b) show influent and effluent concentrations of NH_3–N with a removal efficiency of both reactors.

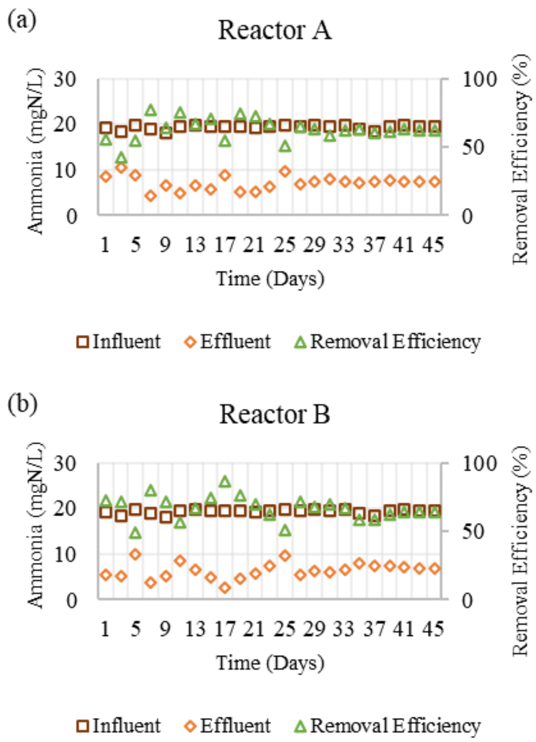

Fig. 6 NH_3-N concentration of influent and effluent with removal efficiency: (a) Reactor A, (b) Reactor B

3.6. Nitrate-Nitrogen (NO_3^-–N)

The average NO_3^-–N concentration of influent was 1.2 mg/L. However, ammonia converted to nitrate due to nitrification; thus, NO_3^-–N concentration increased in the effluent. The steady state of the reactor for NO_3^-–N was achieved at the same period when it attained a steady state for NH_3–N. Figures 7 (a) and (b) represent influent and effluent concentrations of reactors A and B, respectively.

3.7. Sludge Volume Index (SVI)

Fig. 8 illustrates the profile of SVI in both reactors against time. It can be observed that the quality of sludge was intermediate initially. However, when reactors achieved steady state conditions, the sludge quality improved.

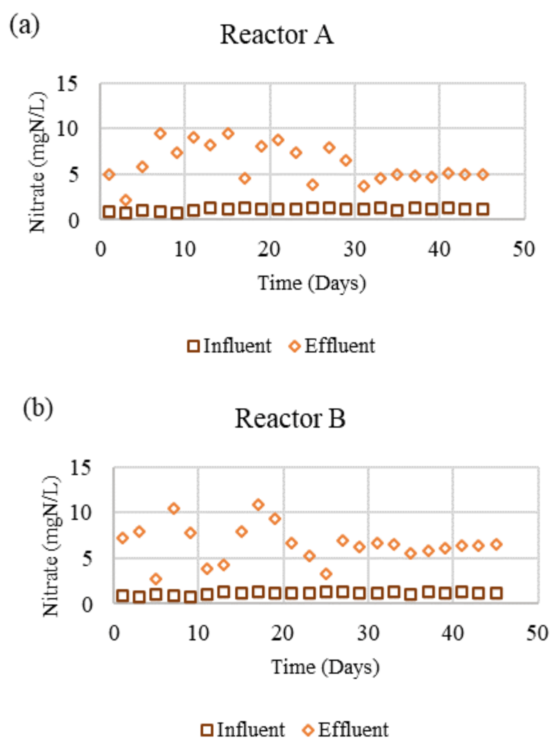

Fig. 7 NO_3^-–N concentration of influent and effluent of (a) Reactor A, (b) Reactor B

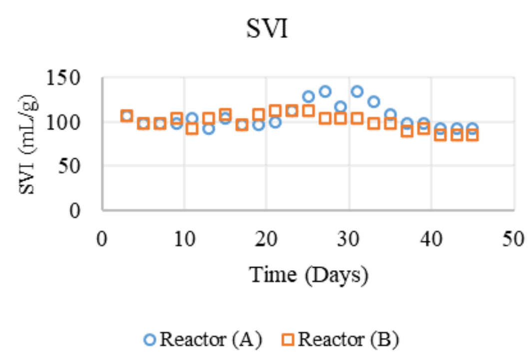

Fig. 8 The SVI profile for both reactors

4. Conclusions

The present study concludes that reactors achieved a steady state for organic removal much earlier than nutrients because aerobic heterotrophic bacteria are fast-growing microorganisms among their competitors. At the same time, nitrifiers are slow-growing autotrophic bacteria due to which reactors achieved a steady state for nutrients later than organics. The NH3–N oxidized to nitrate, which increased the concentration of nitrate in the effluent.

The removal efficiency of the reactor for organic is approximately 90% which makes it suitable for organic removal. However, the removal efficiency of ammonia is approximately 65%, and the total phosphorus removal efficiency is 45%. There is ample feasibility to transform the existing treatment facility into an integrated biofilm reactor system to achieve stringent nutrient removal limits.

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