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Performance of Aerated Submerged Fixed Film Reactor to Treat Domestic Wastewater Containing High Ammonia Loading

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Abstract: The performance of an aerated submerged fixed film bioreactor was evaluated during 45 days. High ammonia loading in domestic wastewater from a huge industry was used as the influent of the experiment. A laboratory experiment was conducted using a bioreactor with 5.6 L capacity operated at different hydraulic retention times which were 6, 8 and 10 h. Return activated sludge from wastewater treatment plant of Jababeka was taken as seed sludge. The influent of the experiment has Chemical Oxygen Demand (COD) loading rate from 1181-1987 g COD m^{-3} day^{-1} and ammonia loading from 134-223 g NH_3-Nm^{-3} day. Results indicated better performance at 10 h retention time that the system was able to achieve 90-93 and 94-99% removal efficiencies of COD and ammonia. Data gained exhibited the R^2 value were 0.87 and 0.85, respectively. The effluent COD an ammonia concentration ranged between 36-60 and 0.4 5 mg/L which lower than the Indonesian national discharge standards which were 80 mg COD/L and 10 mg NH_3-N/L. The present study showed also two conditions of aerobic and anaerobic could be worked in a single bioreactor.

Key words: Aerated, submerged, fixed, film bioreactor, COD, ammonia, domestic wastewater, high ammonia loading rate

INTRODUCTION

Up until now, the main source of river pollutants in Indonesia is suspected to be industrial wastewater whereas domestic wastewater is even more threatening (Truttim and Sohsalam, 2016). One of the contributors to the domestic wastewater with high concentrations of pollutants is domestic wastewater from industrial with increasing numbers of workers every year. The limited area of land for domestic wastewater treatment units in the industry causes the volume accumulation of wastewater in the sump pit, resulting the accumulation of concentrations of Chemical Oxygen Demand (COD) and ammonia in the wastewater. This produces high loads of COD and ammonia in wastewater that can aggravate pollution in surface water (Sawyer *et al*., 2003; Roya *et al*., 2015). In consequences, domestic wastewater treatment is required in accordance with industrial environmental conditions so that COD and ammonia concentrations from the treatment unit meet the quality standards which are 80 mg/L for COD and 10 mg/L for ammonia to prevent and cope with pollution in surface water. The application of Aerated Submerged Fixed Film Reactor (ASFFR) has been widely used to treat domestic wastewater and has several advantages. The ASFFR process is a biological treatment with inherent growth which uses submerged media to support the biofilm on its surface equipped with a diffuser to provide air for aeration (Al-Sharekh and Hamoda 2001; Mohammad *et al*., 2017). Aerated submerged fixed film reactor consist of two zones: aerobic and anaerobic in a single reactor which support nitrogen removal (Kordkandi and khoshfetrat, 2015). The system also has a long sludge retention time thus triggering the growth of nitrifying bacteria and carbon removal (Shore *et al*., 2012). Its ability to degrade wastewater containin carbon and nitrogen at the same time is suitable with the characteristics of domestic wastewater (Khoshfetrat *et al*., 2011; Fauziah *et al*., 2016). Wastewater treatment using ASFFR also requires shorter Hydraulic Retention Time (HRT) less sludge production and capable of processing shock loading (Metcalf and Eddy, 2004).

Short HRT can accelerate the treatment process, especially for treating wastewater with large volume. Determination of optimum HRT for treatment with ASFFR is an important factor in knowing the system performance because it has significant effect to Organic Loading Late (OLR). Short HRT can produce a high organic loading

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rate. While long HRT are suitable for treating wastewater with high COD or BOD concentration and for compounds that difficult to biologically degrade. In this study, domestic wastewater treatment using ASFFR was done with three variations of HRT which were 6, 8 and 10 h. The selection of HRT was based on prior research where HRT ranges from 5-9 h were the optimal HRT for ASFFR (Kordkandi and Khoshfetrat, 2015; Izanloo *et al*., 2007; Shakerhatibi *et al*., 2010). The study was conducted by varying HRT for ASFFR treatment, analyzing its association with COD and ammonia removal efficiency also determining optimum HRT to treat domestic wastewater containing high ammonia loading on ASFF reactor.

MATERIALS AND METHODS

Wastewater: Domestic wastewater obtained from an industry in Jakarta used as the influent. The characteristicsm of domestic wastewater generated from the industry had a variation of concentration every day. Table 1 shows the results of analyzing the influent of samples during the study.

Experimental set-up: The study was conducted on a lab-scale with a scheme as showed in Fig. 1. The ASFF reactor is a cylindrical tube with a height of 90 cm and a diameter of 1 cm made of plexiglas with a working volume of 5.3 L, according to the previous experiment by Kordkandi and Khosfetrat (2015). This bioreactor was filled with 2.5 L of Kaldness K1 support media which divided into three zones. The supporting media had a porosity of 68% and a density of 0.93 g/cm^3, lower than the density of water which makes it floating. On the top of the surface before the effluent valve, a perforated plate was placed to make sure that no supporting media were dry and must submerge in the water to support the biofilm. Every zone was also separated using a perforated plate. The aerobic and anaerobic zones inside the bioreactor were conditioned by giving diffusers that only blow up side at the base of aerobic zones. The wastewater fed into the reactor from the bottom, known as the up flow system. The bioreactor was completed with three valves which were at the upper of anaerobic zone for a ventilation system, lower anaerobic zones for sampling port and upper aerobic zone to discharge effluent. The aeration rates in this study were constant with the airflow rate of 1.5 L/h in each pump on aerobic zones. The wastewater flow rate was adjusted by using a peristaltic pump (D2) which was in a raft with potentiometer to get the desired discharge. The system was equipped with a 20 L tank to accommodate wastewater influent and effluent. The bioreactor was operated at room temperature which was 26±1°C that similar to Indonesian normal temperature especially in Jakarta.

Table 1: Characteristic of wastewater used in the experiments

Parameters	Concentration range
COD	429-828 mg/L
Ammonia (NH_3-N)	56-93 mg/L
BOD_5	225-472 mg/L
pH	6.8-7.5
Biodegradability (BOD_5/COD)	0.52-0.57

System start-up and experimental procedure: At first, seeding or the inoculation process was done by filling 3 L of return activated sludge obtained from the domestic wastewater treatment plant of Jababeka that diluted with 2.6 L distilled water to the bioreactor. The system was operated in batch mode to support the form of an initial biofilm on Kaldness media with duration of 2.5 h on/0.5 h off aeration. The inoculation process was done in 12 days and controlled by measured the parameters of COD, pH, DO and temperature. This inoculation process succeeds when it reaches a steady state condition.

After inoculation, the bioreactor was adapted to wastewater (acclimatization) in two weeks by divided the wastewater into five phases until 100% working volume of the reactor were filled. The wastewater fed into the reactor by using a continuous flow with HRT of 6 at a flow rate of 14.7 mL/min. The average concentration of dissolved oxygen in aerobic zones was 4.07 mg O_2/L. While in the anaerobic zone was always below 0.6 mg O_2/L. The average pH was 7.62 and the steady state condition was achieved with the COD removal efficiency of 89, 95 and 90%. Afterwards, experiments were conducted to study the bioreactor performance.

To evaluate the performance, the bioreactor was fed with wastewater using three variations of HRT which were 6, 8 and 10 h. The process was carried out with HRT 6 h in the first 5 days, 8 h in the next 5 days and 10 h in the last 5 days with the fluctuating concentration of COD and ammonia (Table 1). The given air flow rate was constant at 1.5 L/h in the aerobic zones. Samples influent and effluent of wastewater measured daily to determine the removal of COD, ammonia (NH_3-N) DO and pH.

Analytical procedures: Samples were analyzed daily for influent and effluent COD, ammonia, DO, pH and temperature in accordance with the Indonesian standard methods for examination of water and wastewater. DO, pH and temperature were measured by using a dissolved oxygen meter, pH meter and thermometer (Fig. 2). The COD concentrations of the influent and effluent were

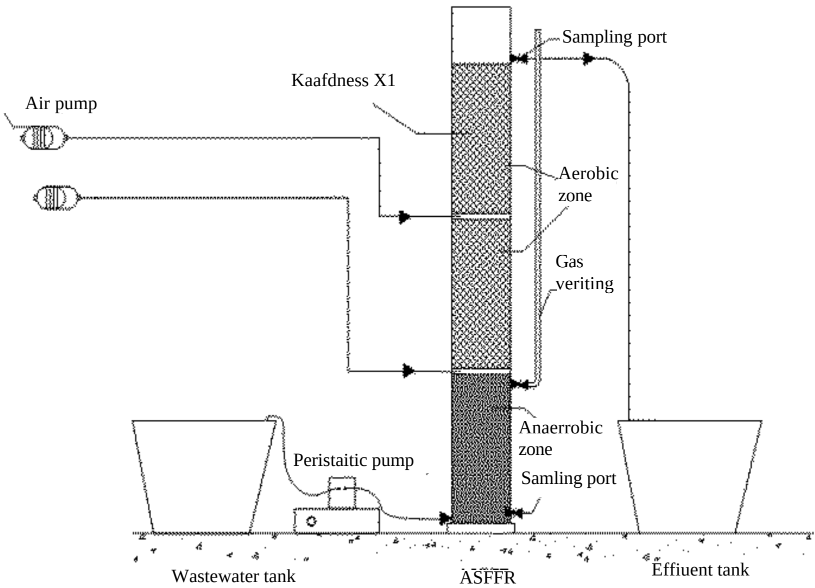

Fig. 1: Schematic diagram of experimental set-up

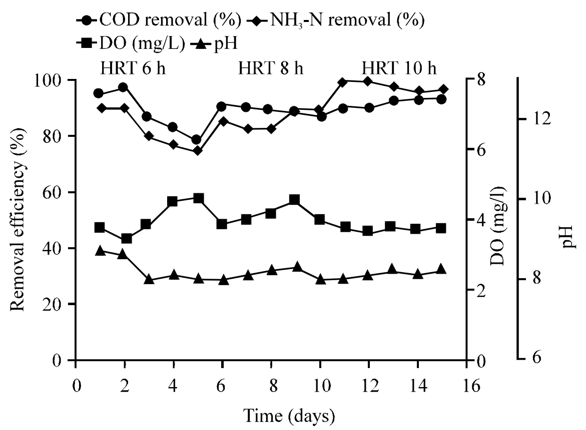

Fig. 2: COD removal efficiency, DO and pH during operational period

Table 2: Data of experimentation in the present study

Time (d)	COD (mg/L)	NH_3-N (mg/L)	HRT (h)	COD/N ratio	OLR (kg COD/m^{3}d)	NLR (kg NH_3-N/m^{3}d)
1	618	89	6	6.94	2.47	0.36
2	615	93	6	6.65	2.46	0.37
3	579	71	6	8.14	2.32	0.28
4	557	75	6	7.45	2.23	0.30
5	525	77	6	6.86	2.10	0.31
6	828	62	8	13.29	2.48	0.19
7	429	68	8	6.31	1.29	0.20
8	451	78	8	5.78	1.35	0.23
9	493	76	8	6.49	1.48	0.23
10	518	81	8	6.40	1.55	0.24
11	478	56	10	8.54	1.15	0.13
12	611	79	10	7.71	1.47	0.19
13	563	87	10	6.47	1.35	0.21
14	640	79	10	8.10	1.54	0.19
15	492	72	10	6.83	1.18	0.17

determined once a day by using spectrophotometer 620 mm While concentrations of NH_3-N were also determined once a day by spectrophotometer in 425 mm wavelength (Nessler) (Table 2).

RESULTS AND DISCUSSION

Effect of dissolved oxygen, ph and loading rates on performance of asffr: The performance of system was examined for 15 days after the end of start-up period. As shown in Fig. 2 operation of the system started from HRT of 6-8 h and last, 10 h. The removal efficiency for both COD and ammonia were significantly different among the three hydraulic retention times with the fluctuated DO concentration. The high DO fluctuation of effluent in 6 h, shows poor degradation of COD and ammonia. The outcome showed a decreased in COD removal at 6 h from 97-78% which was accompanied by a DO increased from 3.83-5.2 mg/L. At the same time, ammonia removal decreased from 89-74%. The removal efficiency showed a more stable result on HRT of 8 h where 91 COD removal efficiency decreases to 87% with an increase of DO concentration from 4.3-5.1 mg/L and reached 89% of NH_3-N removal efficiency. More satisfactory removal result was obtained at HRT of 10 h which has a more stable removal efficiency that can remove COD up to 93% and can decreased NH_3-N concentration up to 99% with the dissolved oxygen concentration at about 4.2 mg/L during the 5 runs (days 11-15). Increased of DO concentrations indicate reduced use of oxygen by bacteria to degrade organic materials that was decreasing

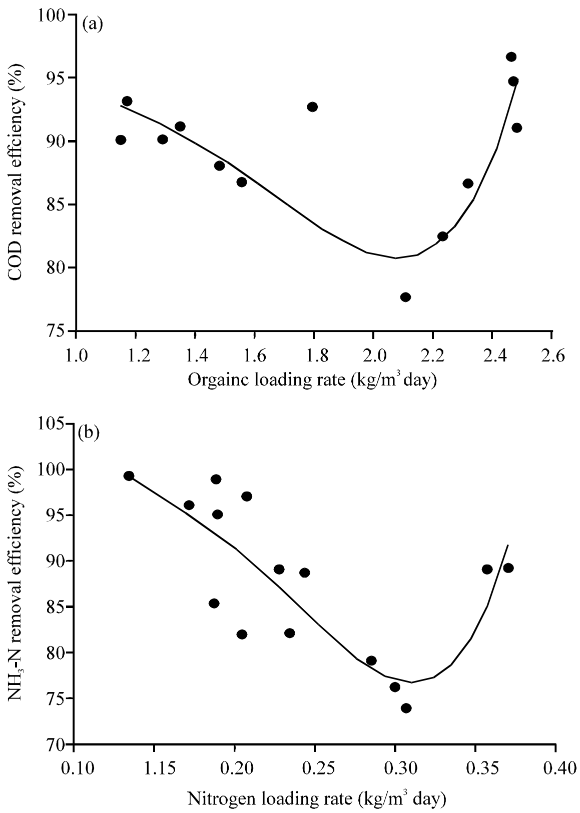

Fig. 3: Variation of loading rate; a) COD removal and organic loading rate and b) NH_3-N removal and nitrogen loading rate

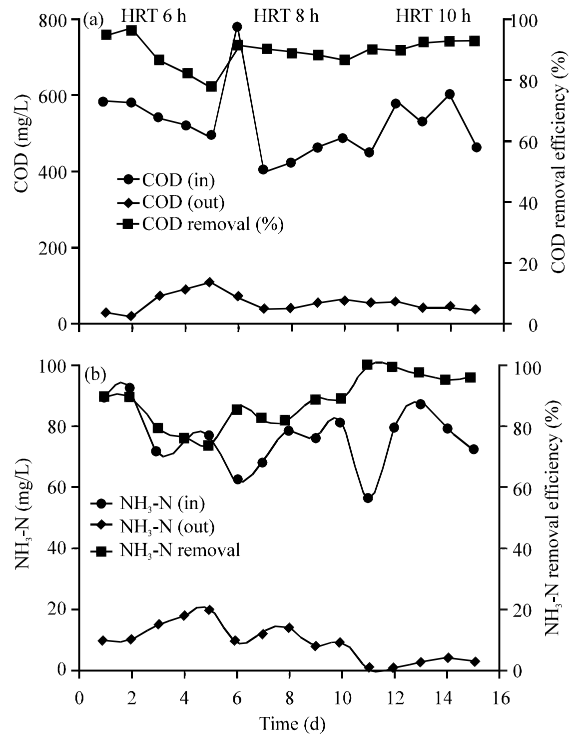

Fig. 4: Performance of the ASFFR for wastewater treatment: a) COD of influent and effluent and COD removal efficiencies and b) Ammonia of influent and effluent and ammonia removal efficiencies

the removal efficiency (days 1-5). DO concentration influence the reaction rate of both ammonia and nitrite oxidation as the co-substrate for nitrification. Thereby, effluent ammonium concentration was decreased when DO concentration was decreased in the aerobic zone (Zafarzadeh *et al*., 2010). Throughout the operation, pH decreased during degradation of organics in the reactor. This was because the work of acid producing bacteria in the anaerobic zone. The pH decrease affected aerobic zones whic h interfere the work of nitrifying bacteria, since nitrification was most efficient at pH levels from 7.5-9.0 (Sajuni *et al*., 2010). DO and pH value were greatly affected the condition of bacteria, thus were affecting the bacterial performance in removing COD and ammonia in wastewater. Therefore, pH adjustment was done to maintain the pH above 7.5 during operation by added NaOH to the influent.

The experimental results showed OLR about 1.14-1.46 kg COD/m^3 day achieved a COD removal efficiency around 90-93 increased OLR up to 2.1 kg COD/m^3 day were resulting removal decrease to 77% (Fig. 3a). Previous research has explained this condition occurred because of simple consumption of carbonaceous materials in both aerated and non-aerated zones. The oxygen mass transfer limitation at high OLR values has a considerable impact on COD removal efficiency at aerated zone but not in non-aerated area led to a reduction in COD removal of the system with increasing loading rates (Kordkandi and khoshfetrat, 2015). Nevertheless, there was a return on the OLR of 2.42 kg COD/m^3 day, achieving a 95% COD removal efficiency. However when the OLR was increased again, removal efficiency went down. Thus, the optimum OLR range was concluded in OLR of 1.14-1.46 kg COD/m^{3}day.

The main parameter concern in this study was ammonia (NH_3-N) where the influent reached 93 mg/L and the Indonesian discharge standard is 10 mg/L which needs at least 90% removal. Ammonia removal efficiency >95% can be achieved when NLR was in the range of 0.13-0.21 kg NH_3-N/m^3 day with DO concentration of 4.05-4.25 mg/L and pH valued of 8-8.1 Fig. 3b shows that lower nitrogen loading rates have a higher ammonia removal efficiency that achieved by setting the HRT-10 h (Fig. 4).

Optimum HRT for asffr to treat domestic wastewater: The result of this study indicated, hydraulic retention time of 6 h still produced COD effluent above the quality standard which 80 mg/L for COD and 10 mg/L for ammonia. When the reactor was receiving a COD influent of 525 and 557 mg/L, the COD removal efficiency decreased to 78 and 825% resulted in an effluent that did not meet the quality standard of 117 and 98 mg/L. While on ammonia removal, HRT of 6 h also still produced effluent that did not meet the standard when received NH_3-N influent of 71.2, 74.8 and 76.5 mg/L with the removal efficiency of 79, 76 and 74% which produced effluent of 14.9, 17.8 and 20 mg/L, respectively (Fig. 4 a).

While HRT of 8 h has resulted COD effluent concentrations that met the quality standard for the whole experiment. The condition of influent anomaly has been successfully treated using HRT of 8 h. It was a COD influent concentration of 828 mg/L, the highest COD during operation which was removed 91% and produced 75 mg/L of effluent concentration. However, for the effluent concentration, the parameter of ammonia still produced two of the five whole data that did not meet the quality standard. In ammonia influent of 68 and 78 mg/L with a removal efficiency of 82% for both and was leaving 12 and 14 mg/L effluents.

Then HRT of 10 h showed the best performance by yielding effluent concentrations for both COD and ammonia complied with the quality standard for all 5 experiments with allowance above 90% each. Effluent for COD was in the range of 36-62 mg/L with a removal of 90-93%. While for ammonia removal was in the range of 95-99% with ammonia effluent concentration of 0.4-3.95 mg/L. The R^2 for 10 h HRT was 0.87 for COD removal and 0.84 for NH_3-N removal.

This condition indicated that the operated hydraulic loading rate was still too large to be processed on ASFFR for HRT of 6 and 8 h to meet the standard value. However, control variables which were pH and DO also affect the ability of ASFFR in removing COD and ammonia because the environmental conditions of water will affect the activity of bacteria *Aspidisca sp.* and nitrifying bacteria. The temperature was also one of the factors that affected the reactor, Indonesia's constant temperature supports the treatment conditions. Then, from the results of removal for both parameters which were COD and ammonia in the feeding process against. This quality standard determines the optimal HRT for ASFFR.

Factors that greatly affect the ability of ASFFR in removing COD and NH_3-N were the hydraulic retention time that also influence the rate of organic loading into the reactor. Determination of the optimal HRT refers to the values of the COD and NH_3-N removal efficiency test results at each variation of detention time. The removal efficiency increased from HRT of 6-10 h t-test detected a significant difference ($p<0.05$) in the COD and NH_3-N removal between the three studied hydraulic retention times for the reactor which means 10 h HRT had better removal than two others HRT significantly. To know the distribution of research data, boxplots presented in Fig. 5. Boxplot is also used to see the minimum removal, whether meet the quality standard or not.

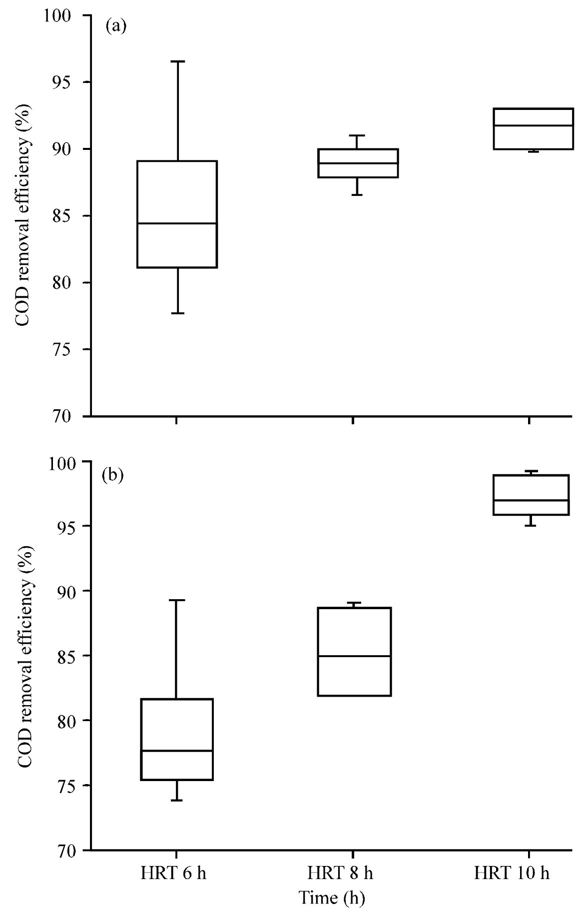

Fig 5: Box plot removal efficiency of: a) COD and b) ammonia (NH_3-N) on ASFFR

At 6 h HRT, whiskers had a considerable range with a bottom line at a 78% removal resulted in effluent COD of 117 mg/L which is beyond the standard quality limit (80 mg/L). Similarly in setting aside NH_3-N, HRT of 6 h had a lower whiskers line at 74% with the effluent above standard quality, 20 mg/L. At HRT of 8 h , the COD removal efficiency had stable data, indicated by a box with a slight altitude. However in the ammonia removal, the lower whiskers had a removal of 82% which resulted in 14 mg/L ammonia effluents, exceeding the quality standard. Thus, 8 h HRT was not selected as optimal HRT. At 10 h HRT, minimum COD removal efficiency was 90%, resulted COD effluent of 60 mg/L. While for ammonia removal efficiency, lower whiskers had 95% but still produce effluent under the quality standard. Both of COD and ammonia effluent under the quality standards were in accordance with the purpose of this study. Therefore, RT of 10 h was chosen as the optimum detention time to removes COD and NH_3-N from the industrial domestic wastewater with aerated submerged fixed film reactor.

CONCLUSION

An ASFF reactor with kaldness k1 as the supporting media was used to removed carbon and nitrogen from domestic wastewater containing high ammonia loading. Organic and nitrogen loading rates were varied in ranges of 1.2-1.987 kg COD/m^3 day and 0.134-0.223 kg NH_3-N/m^3 day. To evaluate the optimum HRT for ASFF reactor, HRT was changed during the experiments from 6, 8 and 10 h. ASFFR reached 97% for COD removal with effluent concentration of 21 mg/L at HRT of 6 h. However, at the end, HRT 10 h has the most stable value with COD and ammonia removal ranges of, respectively (90-93)% and (95-99)%. While effluent for COD and ammonia parameters were (36-62) mg/L and (0.4-3.95) mg/L, respectively.

Optimum HRT is needed to process domestic wastewater so that the effluent of the processing fulfil the quality standard of Jakarta Gubernatorial Regulation No. 122 in 2005 which were 80 mgCOD/L and 10 mg NH_3-N/L. It is concluded that the most optimum HRT for treating domestic wastewater is 10 h which can produce COD effluent to 36 mg/L and the effluent of ammonia reached 0.4 mg/L. The system also showed an acceptable performance to remove carbon and nitrogen simultaneously for high ammonium level of influent. Although, the use of ASFFR system has been reported for the treatment of various wastewater, not much research on ASFF reactor performance for domestic wastewater produced from industrial is studied. Especially on the condition of Jakarta which has many industries but with limited area.

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