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Comparison Study of AN Removal in Different Geometrical Shape of a Pilot-scale Aerated EAFS Filter Systems

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Abstract: Two types of aerated electric arc furnace slag filter systems in dissimilar geometry shape; the vertical upward-flow and horizontal-flow were studied in treating domestic wastewater in a tropical climate country. These filters were operated at the same hydraulic loading rate (HLR) set-up of 2.72 m^3/m^3.day and the removal efficiency of the contaminant was studied and analyzed. Air was supplied to both systems at 10 L/min and the observation of dissolved oxygen concentration on ammonium nitrogen (AN) removal were finally compared. The results revealed that both systems were efficiently able to produce ammonium nitrogen (AN) removal of more than 85%; however with regard to individual's system performance, the vertical upward-flow electric arc furnace slag filter (VFEAFS) system was found excellent than the horizontal-flow electric arc furnace slag filter (HFEAFS) system. The mean value of AN effluent concentration equally by the systems were discovered easily to follow regulated standard A of Malaysian sewage discharge limit (10 mg NH_4-N/L). The results obtained in this pilot-scale study indicated that the geometry shape of filter system has the effect on the removal of ammonium nitrogen, particularly in the aerated VFEAFS system due to their capability to produce higher and uniform oxygen distribution in the whole filter system, and eventually resulted in a lower AN effluent concentration rather the one operated in the horizontal-flow direction. Based on these findings, it is also recommended that further study on the aerated rock filter should be evaluated for the other parameters (total kjedahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), pH, and alkalinity) which on the other hand are believed possess the potential to accommodate nitrification process in the system and eventually eliminate nitrogen pollutant from domestic wastewater.

Keywords: Electric arc furnace slag, ammonium nitrogen, vertical upward-flow, horizontal flow

1. Introduction

Filtration is known as one of the oldest, simplest and most widely used method in water treatment. In this process, raw wastewater containing suspended solids is removed by passing the liquid through a porous bed materials or permeable fabric. The constructed wetlands (CW) and rock filter (RF) are the most usual natural treatment systems that employed the filtration method. Despite the capability of CW system to remove variety of contaminant including nutrients, the system however was identified to become phosphorus-saturated within several years and begin discharging excessive amounts of phosphate [1]. In placing more emphasis, Drizo et al. [2] claimed that the wetland was inefficient to eradicate phosphorus contaminant from wastewater after it was operated between 2 or 5 years. Moreover, the inadequate of dissolved oxygen in the CW has contributed disadvantage to the system in the case of nitrification process as the nitrifying bacteria is competing with organics for inadequate DO and eventually, inhibited the process of nitrogen removal [3].

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Nowadays, the engineered system that is invented to imitate the subsurface CW operation is the RF system. The system is grouped into two general types; horizontal flow and vertical flow systems; and can be operated whether in downward or upward direction. The application of rock filter system was started and widely used in the United States for nearly 40 years ago; principally for algal suspended solids and organic matter (BOD) removals using the unaerated rock filter (URF) system [4]. Nevertheless, this URF system which implement identical idea as in the CW has encountered the same drawback since the system was rapidly become anoxic, as there is no (or very little) ammonium nitrogen (AN) removal was observed [5]-[7].

Therefore, in 2005 several researchers from United Kingdom had initiated a study which implements the use of aerated rock filter (ARF) to improve wastewater quality parameter (BOD, TSS, faecal coliforms) as well as ammonium nitrogen removal [8], [9]. A good removal of AN was observed by the researchers in the vertical-flow type of ARF system [10]. Thus, considering the needs to increase oxygen availability in the RF system, a continuous aeration was introduced in the present study as it has proven in the previous research to provide sufficient oxygen, and eventually facilitate effective nitrification in the system [5]. Hence, the present study was initiated to examine the performance of pilot-scale of ARF systems of different geometrical shape (the vertical upward-flow and horizontal flow) systems in treating AN from wastewater. The aim was to observe removal trend of ammonium nitrogen in the ARF systems that treated domestic wastewater in tropical climate country using electric arc furnace slag (EAFS) as the filter medium and as has been suggested by the previous researchers [5]. In the current study, a combination of existing wastewater treatment system; the wastewater treatment plant (WWTP) grit tank, together with the proposed system; the proposed primary tank (PPT) and ARF systems either operated in vertical upward-flow or horizontal flow was monitored specifically in removing ammonium nitrogen. The systems previously have shown to be a good low-cost technology, have low energy requirements and do not require highly skilled personnel [11] in treating municipal wastewater.

In spite of complying with the strict regulations as has been legislated in the Malaysian Environmental Quality (Sewage) Regulations 2009 (PU(A) 432) Second Schedule (Regulation 7) [12] on the elimination of nitrogen particularly ammonium nitrogen (AN) from wastewater, the effluent discharge limit of AN to water body is limited not exceeding 10 mg/L for standard A; 20 mg/L for standard B. It is therefore, necessary for conventional wastewater treatment systems to be updated or the treatment scheme should be extended with a polishing treatment [13]. Thus, the combination of conventional and ARF application systems are believe to possibly generate a high quality of final effluent with the utilization of a low-cost media technology. Ultimately this technology is understood to be the best alternative for removal of AN in the case of small communities looking for high quality of final effluent. The research described here concerns the removal of AN from wastewater treatment plant influent using an efficient and low maintenance of both aerated EAFS (the VFEAFS and HFEAFS) filter systems.

2. Materials and Methods

2.1 The Pilot-scale of Aerated Vertical Upward-Flow and Horizontal-Flow of EAFS Filter System Set-Up

The pilot scale of aerated VFEAFS filter system were constructed from 10-mm thick PVC pipe of 0.3 m diameter by 2.0 m high; allowing wastewater to flow at 1.5 m deep. On the other hand, the HFEAFS unit was built from 102 mm of concrete block and coated with water-proof layer. The dimension of the filter is 1 m long by 0.3 m wide by 0.5 m high. Both systems (the VFEAFS and HFEAFS filters) were allowed to flow wastewater at freeboard of 0.5 m and 0.1 m, respectively; which, permitting the filter to operate in subsurface flow condition and as a result, preventing algal growth within the EAFS filter systems. The filter systems were filled with the entirely electric arc furnace slag of high Ca composition and placed at Taman Bukit Perdana wastewater treatment plant (WWTP), situated in Batu Pahat, Johor, Malaysia. Technically, this WWTP receives screened domestic wastewater of 90% and was largely originated from residential area of 15,800 population equivalent (PE), and the remaining percentage (10%) is from industrial area. Fig. 1 and Fig. 2 illustrate the pilot scale of horizontal-flow and vertical upward-flow of EAFSs system at study site location.

Fig. 1 - The pilot scale of horizontal-flow EAFS system at site location

Fig. 2 - The pilot scale of vertical upward-flow EAFS system at site location

In general, this experimental study utilized a primary sedimentation treatment system (proposed primary tank) and a secondary treatment systems (the vertical upward-flow and horizontal-flow). Earlier, the after pre-treatment of screened wastewater from the existing grit and grease tank of WWTP was pumped to the proposed primary tank (PPT) using Masterflex peristaltic pump, model Cole Parmer 7524-20, USA equipped with Masterflex easy load pump head, model Cole Parmer 77200-62, USA. The influent wastewater was flowed to the PPT using 25.4-mm reinforced plastic pipework and connected with polyvinyl chloride (PVC) inlet strainer.

The wastewater effluent after PPT was then permitted to flow into the pilot scale of secondary treatment systems (the vertical upward-flow and horizontal-flow systems) using similar Masterflex peristaltic pump and Masterflex easy load pump head models, located at the base of the aerated VFEAFS filter systems, and were connected with 9.7-mm Masterflex platimum-cured silicone tubing L/S 36, model Cole Parmer EW-96410-36, USA. Both filters; the VFEAFS and HFEAFS of similar HLR (2.72 m^3/m^3.day) were aerated using an oil-free compressor, model Jun-air International OF 302-25B, Denmark supplying a 250-mm fine bubble rubber disk aerator, model Biwater Treatment, England with air flow maintained at 10 L/min. The feeding of air flow rate to the fine bubble rubber disk aerator was regularly maintained using a float-and-tube air flow meter. The set-up of experimental study layout of the above-mentioned case is presented in Fig. 3.

The influent sample after passing pre-treatment process from the existing grit and grease tank of WWTP, as well as the effluent samples from PPT, and aerated VFEAFS and HFEAFS of similar HLR were collected bi-weekly and analyzed for ammonium nitrogen (AN) concentrations; according to the Standard Methods for the Examination of Water and Wastewater [14] procedures. In addition, the in-situ parameters (dissolved oxygen, pH and temperature) of weekly grab samples of WWTP grit tank influent, PPT and both aerated VFEAFSs filter effluents were measured using a portable DO meter, model Hanna HI 9146, Italy and portable pH meter, model Hanna HI 991301, Italy.

Measurement of oxygen distribution taken from sampling taps at the outer surface of column filter was also conducted at different depths (0.50 m, 0.75 m, 1.00 m, 1.25 m, and 1.50 m) of the aerated VFEAFS filter systems. Meanwhile, five perforated 25.4 mm PVC sampling pipes were arranged lengthwise in the filter at 0.2 m, 0.4 m, 0.6 m, 0.8 m, and 1.0 m from filter inlet to permit sampling of dissolved oxygen concentrations in wastewater at the base, middle and top of HFEAFS system. The purpose was to examine oxygen distribution concentration that had accommodated AN removal in both of the treatment systems. Finally, the performance of both aerated VFEAFS and HFEAFS filter systems on the monitored AN parameter was expressed as their percentage of removal efficiencies and computed using the following equation.

$$\text{Removal efficiency (\%)} = \left[\frac{C_{in}-C_{out}}{C_{in}}\right] \times 100 \quad (1)$$

where C_{in} is the mean value of inflow concentration (mg/L) and C_{out} is the mean value of outflow concentration (mg/L).

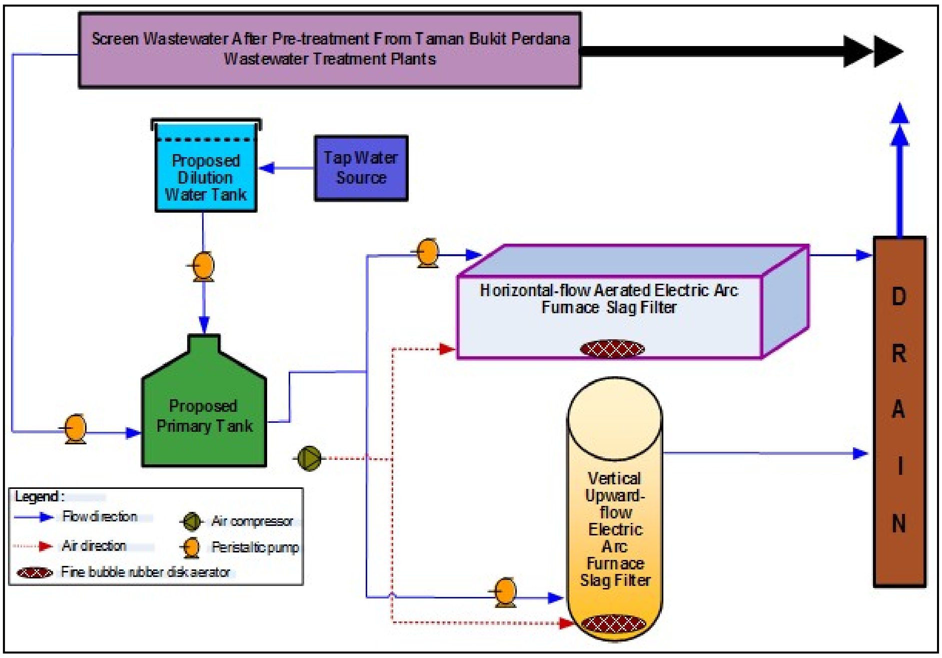

Fig. 3 - The ARFs (HFEAFS and VFEAFS) pilot-scale treatment systems layout experiment

3. Results and Discussion

3.1 Dissolved Oxygen and Temperature of Aerated VFEAFS and HFEAFS Filter Effluents

The aerated vertical upward-flow filter was demonstrably fabulous in comparison with the aerated horizontal-flow filter concerning dissolved oxygen concentration in the system. The VFEAFS system with 1.5 m depth was observed to be more oxygenated rather than the HFEAFS system with 0.4 m depth. Initially, effluents from PPT system containing DO concentration at range of 0.39 – 1.44 mg O_2/L were aerated as soon as it entered the aerated EAFS filter systems. The VFEAFS filter system had shown an impressive capability in generating a high DO concentration at range of 3.60 – 5.43 mg O_2/L; whilst the HFEAFS filter system had moderately produced DO concentration at range of 2.56 – 4.32 mg O_2/L. These trends are well described in Fig. 4. Furthermore, DO effluent concentrations found in the aerated VFEAFS filter system were observed greater than 3 mg O_2/L in most occasions; accordingly had improved nitrification rate as has been pointed out by Gerardi [15]. Hence, in a well oxygenated system; for instance in the 1.5 m depth of aerated EAFS filter (the VFEAFS), greater of ammonium ions were oxidized to nitrate-nitrogen (NO_3-N); in comparison with 0.4 m depth of EAFS filter (the HFEAFS); indicating that high level of nitrification rate had occurred in the aerated VFEAFS filter system.

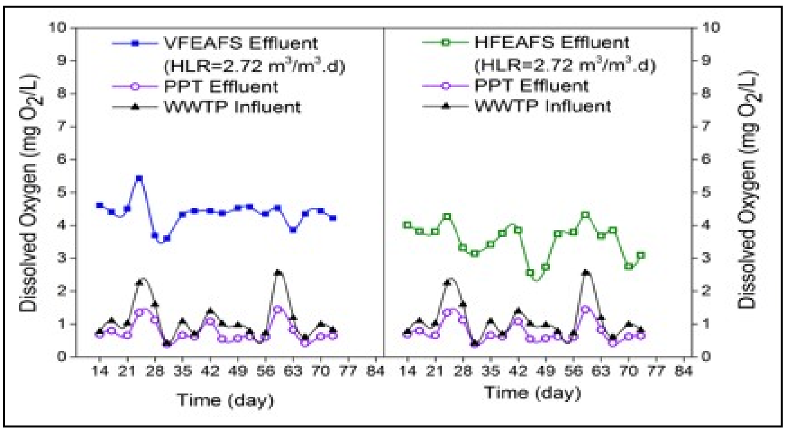

Fig. 4 - DO effluent concentrations of different geometry shape of aerated EAFS filter (vertical upward-flow and horizontal-flow) systems

At the same time, the growth of nitrifying bacteria is scientifically regulated by temperature variations. According to Gerardi [16], the range of temperature between 8-30°C is significantly influenced the growth rate of nitrifying bacteria; owing to the fact that an increment of 1°C temperature above 8 °C accordingly, will increase the growth rate of *nitrosomonas* at almost 10%. During 73 days of monitoring period, influent wastewater temperature from WWTP grit tank was measured at range of 28.00-35.43 °C. As influent wastewater entered PPT system, the range of temperature was observed at 28.23 – 32.40 °C; which on the other hand was not obviously changed or affected. Later, the effluent wastewater from PPT system flowed into aerated EAFS filter system of different geometry shape (the VFEAFS and HFEAFS); yet at same HLR operation (2.72 m^3/m^3.day). Their effluent temperature data were more or less consistent at range of 27.30 – 32.10 °C for vertical upward-flow system; while 27.60 – 31.60 °C for horizontal-flow system. Thus, it is entirely fanciful to suggest that the effluent temperature data obtained from both systems had indirectly accommodate biological processes for organic matter, and total nutrients removal to appear in the treatment system including nitrification and denitrification activities [16]-[19]. Fig. 5 compiles the variations of temperature data from WWTP grit tank influent, PPT and EAFS filters effluents systems.

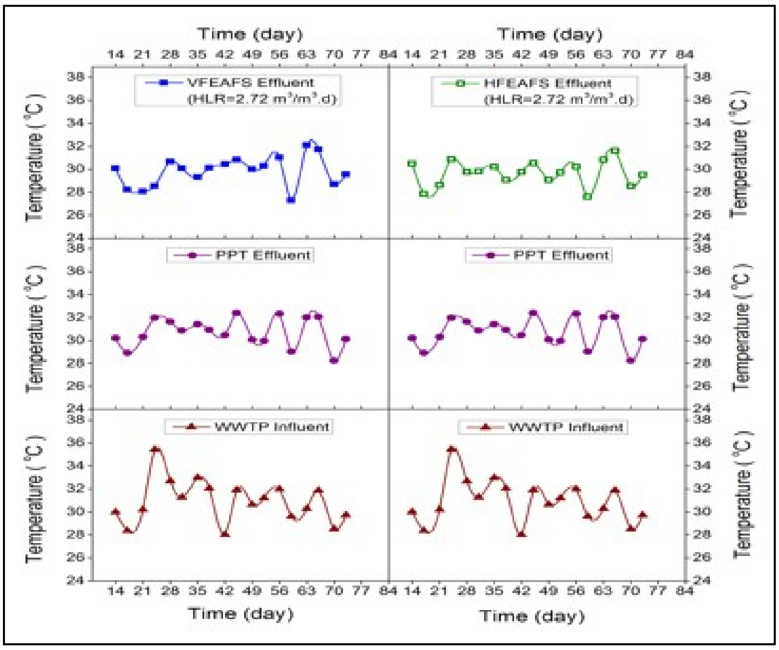

Fig. 5 - Effluent temperature of different geometry shape of aerated EAFS filter (vertical upward-flow and horizontal-flow) systems

Table 1 - Summary of statistical data for aerated vertical upward-flow and horizontal-flow EAFS filter systems performance at different geometry shape[a]

Statistical data	Sampling point		Parameter		
			T	DO	AN
Concentrations (mg/L)	Influent	WWTP	30.9±1.8	1.1±0.5	28.6±5.7
	Effluent	VFEAFS (HLR = 2.72)	29.8±1.3	4.4±0.4	1.8±0.4
		HFEAFS (HLR = 2.72)	29.7±1.	3.6±0.	3.4±0.
Removal efficiency (%) (mean ± s.d)	WWTP + PPT		n.a	n.a	26.1±8.3
	WWTP + PPT + VFEAFS (HLR = 2.72)		n.a	n.a	93.7±1.2
	WWTP + PPT + HFEAFS (HLR = 2.72)		n.a	n.a	87.9±2.2

[a]Note : All units are in mg/L except for T = Temperature (°C); DO = Dissolved oxygen; AN = Ammonium nitrogen; s.d = standard deviation (n =18); n.a = not available; WWTP = Wastewater treatment plant; PPT = Proposed primary tank; VFEAFS = Vertical upward-flow of electric arc furnace slag; HFEAFS = Horizontal-flow of electric arc furnace slag; HLR = Hydraulic loading rate (m^3/m^3.day).

In brief, the average values and standard deviation of removal efficiency of combined aerated EAFS filter systems (WWTP + PPT + VFEAFS; WWTP + PPT + HFEAFS) which were operated at same hydraulic loading rate of 2.72 m^3/m^3.day are summarized in Table 1. As a rule, the combination of proposed primary tank (PPT) and aerated EAFS filter systems in treating contaminant was obviously very efficient in attaining ammonium nitrogen (AN) removal at higher percentage value. The concentration of AN of both aerated VFEAFS and HFEAFS filter systems were far below the permissible limit of Standard A of sewage discharge legislated by Malaysian Environmental Authority (10 mg NH_4-N/L). AN impurity from domestic wastewater were removed effectively in the vertical upward-flow system after secondary treatment. On the whole, in terms of individual system performance, the VFEAFS filter system performed better than the HFEAFS filter system in producing a high ammonium nitrogen removal (more than 90%).

3.2 Distribution of Dissolved Oxygen Inside the Aerated VFEAFS and HFEAFS Filter Systems at Different Lengths and Stages

It is entirely admitted by previous researchers [20], [21] that the anoxic-oxic (AO) condition promotes a significant effect on biological nutrients removal processes in wastewater treatment system. During oxic condition which is only occurred in a well aerated system; nitrifying bacteria namely, *nitrosomonas* and *nitrobacter* would consume an amount of inorganic carbon sources to transform ammonia to nitrite and subsequently to nitrate, and this process is called nitrification. However, the nitrification process itself is incapable to provide nitrogen removal in overall; it should be followed by denitrification process which only exists in anaerobic zone.

Apparently, such condition is likely to occur in a well aerated of horizontal-flow system (middle air diffuser case). The air diffuser that was placed in the middle of HFEAFS filter system had allowed oxygen to uniformly transfer to the wastewater; as a result increase the DO level. Additionally, there was an even more interesting information discovered in this case; both oxic and anoxic zone had appeared simultaneously inside the HFEAFS filter system. As illustrated in Fig. 6, the oxic zone where the dissolved oxygen was measured more than 2 mg O_2/L was observed to appear in the middle and upper of sewage level. On the other hand, the anoxic zone (DO < 2 mg O_2/L) was witnessed to occur at the bottom of sewage level concurrently. This occasion had given an advantage to the aerated horizontal-flow system to achieve better nutrient removal efficiency in comparison with the vertical upward-flow system at similar HLR condition.

On the other perspective, the nitrification process was discovered solely to appear inside the aerated vertical upward-flow system. The concentration of dissolved oxygen was absolutely remarkable higher (3.27 – 5.44 mg O_2/L) unlike in the aerated horizontal-flow type system; creating the aerobic condition to occur uniformly in a well aerated of vertical upward-flow system. Nonetheless, this system was capable to provide only nitrification instead of denitrification which was truly to admit; had limited the complete nitrogen removal to present as a whole.

3.3 AN Removal Efficiency in the Aerated Vertical Upward-Flow and Horizontal-Flow of EAFS Filter Systems

In the beginning of wastewater flow path treatment, influent concentration of AN were analyzed at range of 18.67 – 38.92 mg NH_4-N/L. These concentrations were lessened slightly at range of 14.56 – 26.88 mg NH_4-N/L after underwent PPT system which creates average removal efficiency of 26%. Moreover, the capability of both vertical upward-flow and horizontal-flow of aerated EAFS filter systems were amazingly impressive where each system was able to produce average removal efficiency of AN at 88% (HFEAFS) and 94% (VFEAFS). Nevertheless, in respect of filter's performance the VFEAFS was exhibited better than the HFEAFS system. Final effluent concentrations of VFEAFS and HFEAFS filter systems were at range of 1.37 – 2.80 mg NH_4-N/L and 2.24 – 5.04 mg NH_4-N/L; respectively. The trend of AN effluent concentration of both aerated EAFS systems were relatively constant and obviously fulfil the Standard A requirement where their values were determined very far from the discharge consent limit (10 mg NH_4-N/L). Fig. 7 describes the trend of AN influent and effluent concentrations during the monitoring period programme as well as their removal efficiencies.

4. Conclusion

In conclusion, the aerated VFEAFS filter system was determined efficient than HFEAFS filter system in minimizing ammonium-nitrogen concentration which accordingly, obey with Malaysian regulations of sewage discharge limit. Noticeably, the monitored of AN effluent parameter were constantly below the permissible limit of Standard A. Furthermore, it was discovered that the aerated horizontal-flow EAFS filter system perform nearly similar to the earlier system; however, their final effluent quality was slightly higher than that ran in the vertical upward-flow filter setup. In the first case, a higher concentration of DO effluents indicated that additional free AN ions were converted to nitrate, which eventually had resulted in a high removal of ammonium nitrogen. Therefore, the aerated vertical upward-flow EAFS filter system which owns taller filter depth (1.5 m) than the aerated horizontal-flow EAFS filter system (0.4 m) had maintained greatly effective system for nitrification process at HLR of 2.72 m^3/m^3.day, especially in tropical climate conditions, as in the country of Malaysia.

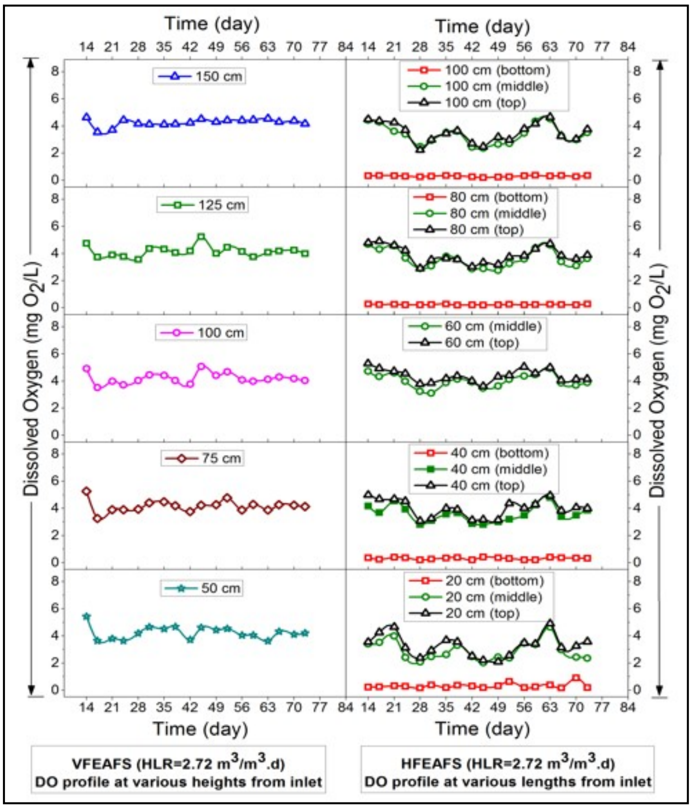

Fig. 6 - DO distribution of different geometry shape of aerated EAFS filter (vertical upward-flow and horizontal-flow systems) at various height intervals and along longitudinal direction under similar HLR operation

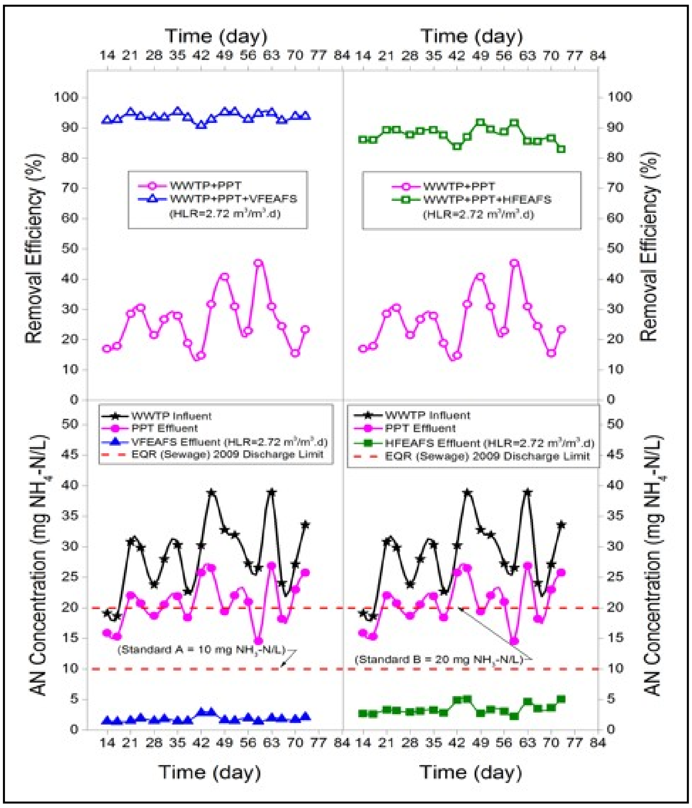

Fig. 7 - AN concentrations and removal efficiencies in the influent (WWTP) and effluents (PPT, VFEAFS filter and HFEAFS filter) sampling locations at similar HLR condition

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