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Effect of Electromagnetic Field on Low Dissolved Oxygen Wastewater Treatment

Nulhazwany Abdul Malik, Khalida Muda, Nur Syamimi Zaidi, Mohamad Darwish*, Ahmad Hanis Omar@Omri

School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310, Johor Bahru, Malaysia

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Abstract

Activated sludge (AS) system is a biological treatment process that is widely applied in municipal wastewater treatment. Concentration of the dissolved oxygen (DO) is one of the important parameters that may influence the performance of AS system. Thus, certain levels of DO in AS systems should be maintained to achieve high efficiency of pollutants removal. However, the energy consumption of aeration stage represents approximately 50% of total demand of AS system. Therefore, reducing aeration energy would improve the feasibility of AS process. This study investigated the enhancement of AS process under low DO condition using electromagnetic field (EMF). The AS was exposed to EMF at intensity of 3 mT with DO concentrations of 1 and 2 mg/L for 24 hours. The impact of EMF on the biomass concentration, settling velocity, sludge volume index and pollutants removal were thoroughly investigated. The results indicated significant improvement in the physical properties of AS exposed to the EMF, which resulted with high accumulation of biomass concentration. The settling velocity and sludge volume index value of the biomass at the end of the experiment were 95 m/h and 72.6 mL/g, respectively. The reactor exposed to EMF under 2 mg/L of DO showed the highest removal efficiency of chemical oxygen demand (80%) ammonia (97%), nitrite (99%), and total nitrogen (84%). Additionally, it was proved that EMF could enhance the settleability of the AS in the treatment system.

Keywords: Electromagnetic field, Activated sludge, Biomass, Nitrate, Ammonia nitrogen

1 Introduction

The rapid development of humans' communities leads to huge increase in wastewater generation (1). Population explosion and expansion of urban areas raise the adverse impacts on water resources, especially in regions where natural resources are restricted. This phenomenon reflects the significant growth in default volumes of wastewater, which makes it an urgent imperative to develop effective and affordable technologies for wastewater treatment (2).

Recently, a tremendous increase in the applications of electromagnetic fields (EMFs) appeared in different domains including therapeutic and diagnostic medicine, environmental managements, and industrial procedures (3). Magnetic technology is a physical treatment technique that was introduced to avoid the consumption of chemicals such as polyphosphates or corrosive substances, which are expensive and can be harmful to the environment and most importantly, human health. This technology has been implemented in various ways through the application of either permanent magnets or high-gradient magnetic separation (HGMS) in combination with magnetic seeding or magnetic adsorption (4). To date, magnetic field was applied for the removal of heavy metals (5), organic compounds (6, 7), nutrients consisting of nitrogen and phosphorus compounds (8, 9) and turbidity and suspended solids (10, 11). Generally, most of the mentioned treatment processes have shown significant improvements under specific magnetic applications (4

Activated sludge process is one of the aerobic biological treatment methods, which is employed as a core process in more than 90% of the municipal wastewater treatment plants (12). Yet, due to the fluctuation of wastewater quality and flow, conventional activated sludge shows a variety of drawbacks, including sludge expansion, loose flocs structure as well as biomass deficiency (13). In addition, the energy consumed by the aeration process represents approximately 50% of the total energy usage of the activated sludge process, which can be dramatically reduced by decreasing the operating dissolved oxygen (DO) concentration (14). However, according to Holenda, Domokos (15), DO levels in the aerobic reactors have significant influence on the behaviour and activity of the heterotrophic and autotrophic microorganisms that live in the AS system.

Limitation of DO concentration often results in poor flocculated sludge and more turbid effluents (16). On the other hand, an excessively high DO, which requires a high air flow rate, leads to a high energy consumption, and may deteriorate the sludge quality as well. Moreover, high DO concentration in the internally recirculated water reduces the efficiency of denitrification process. To the best of our knowledge, the enhancement of municipal wastewater treatment using EMF

Corresponding author: Mohamad Darwish, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310, Johor Bahru, Malaysia. Email: sjmohamad@utm.my.

under the condition of low DO concentration was never tested before. The present study was therefore aimed at investigating the feasibility of applying an EMF in maintaining high effluent quality in municipal wastewater treatment under low concentration of DO. Specifically, objectives of this study are: (1) to identify the effect of EMF on the physical properties of municipal wastewater (i.e. mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), settling velocity and sludge volume index (SVI)); and (2) to analyse the impact of EMF on the removal of chemical oxygen demand (COD), ammonia, nitrite, nitrate and total nitrogen (TN).

2 Materials and methods

2.1 Municipal wastewater characteristics

Raw samples of municipal wastewater, as well as sludge biomass, were collected twice a week from a sewage treatment plant and stored under 4°C. Table 1 shows the main characteristics of municipal wastewater used in this study.

Table 1: Characteristics of municipal wastewater

Parameter	Values
Temperature (°C)	22-27
pH	8.1
COD (mg/L)	103-431
Ammonia (mg/L)	18.25-41.5
Total Nitrogen (mg/L)	24-74

2.2 Experimental setup

Figure 1 shows a schematic diagram of a sequential batch reactor (SBR) used in this study. The SBR consists mainly of three identical glass columns (Column A, B and C) with a total volume of 1,300 mL for each column. A copper coil was attached to Column B and C (Figure 1), which supplied the EMF with an intensity of 3 mT, while Column A was not exposed to EMF and kept as a control. Each column was supported with a stone air diffuser located at the bottom of the column, to provide the system with the required aeration. The concentrations of DO in Column A, B and C were maintained at 3, 2 and 1 mg/L, respectively. The level of DO concentration was monitored using YSI dissolved oxygen meter (USA). The aeration intensity was continuously monitored to ensure that the level of DO concentration was within the specified range. During the start-up period, 200 mL of activated sludge and 800 mL of raw municipal wastewater were added into each column, to compose a working volume of 1,000 mL with a total biomass concentration of 2,000 mg/L. The cycle time of the SBR was 24 hours, consisting of 2 min for feeding reaction, 23.4 h for aerobic reaction, 30 min for settling and 2 min for discharge.

For the physical characteristic's determination, the samples were collected once a week at the middle part of the glass column, and were used to analyse MLSS, MLVSS, settling velocity and SVI. With regards to the performance analysis, the samples were collected twice a week and centrifuged for 5 minutes at 6,000 rpm. The supernatant was used to measure the removal performance of COD, ammonia, nitrite, nitrate and total nitrogen.

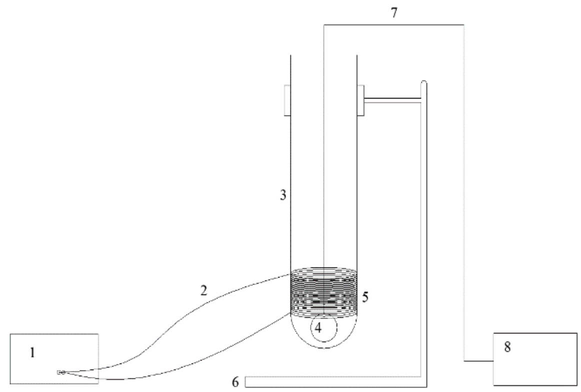

Figure 1: Schematic diagram of the experimental setup (1: DC Power supply, 2: Crocodile clip, 3: Column, 4: Stone diffuser, 5: Copper coil, 6: Retort stand, 7: Tube, 8: Aquarium pump)

2.3 Analytical methods

The concentrations of MLSS and MLVSS were measured based on Methods No. 2540D and 2540E, respectively (APHA, 2005). The settling velocity was determined by recording the average time taken for the individual sludge to settle at a certain height in a glass column filled with tap water (17). In this study, a 16 cm glass column was used to test the settling velocity. Total nitrogen, COD, nitrite, and nitrate concentrations were measured using HACH (DR 6,000) spectrophotometric standard methods, while ammonia nitrogen was analysed using Nessler method.

3 Results and discussion

3.1 Effect of EMF on wastewater physical properties

The physical properties observed in this study included biomass concentration, settling velocity and SVI.

3.1.1 Biomass Concentration

The profile of biomass concentration (MLSS and MLVSS) is given in Figure 2(A) and (B). Generally, it can be seen that the MLSS in Column B was higher than in Column A and C. The average of MLSS for Column B was 2425±33.2 mg/L, while in Column A and B the average was 1,720±28.3 and 1,625±7.2 mg/L, respectively. At steady state, MLVSS for Columns A, B and C were 368.6±5.8, 438.6±5.8 and 238.6±5.8 mg/L, respectively. Throughout the experiment, both MLSS and MLVSS in Column B showed stable reading. Meanwhile, in Columns A and C, sudden drops were observed in the middle of the experiment. The high MLSS and MLVSS in Column B was probably due to the effect of EMF applied to Column B. Principally, magnetic field could influence the microbial community composition and metabolisms, which could further affect the biomass characteristics (18-20). According to Zieliński, Cydzik-Kwiatkowska (21), this higher concentration in biomass resulted from the improved absorption and coagulation in the sludge particles due to the effect of magnetic field. In Column A (no EMF exposure), the molecules moved in random manner, while in Column B and C, the exposure to magnetic field allowed the molecules to align easily according to their positive and negative charges. Consequently, the molecules were arranged orderly, thus able to induce coagulation (22).

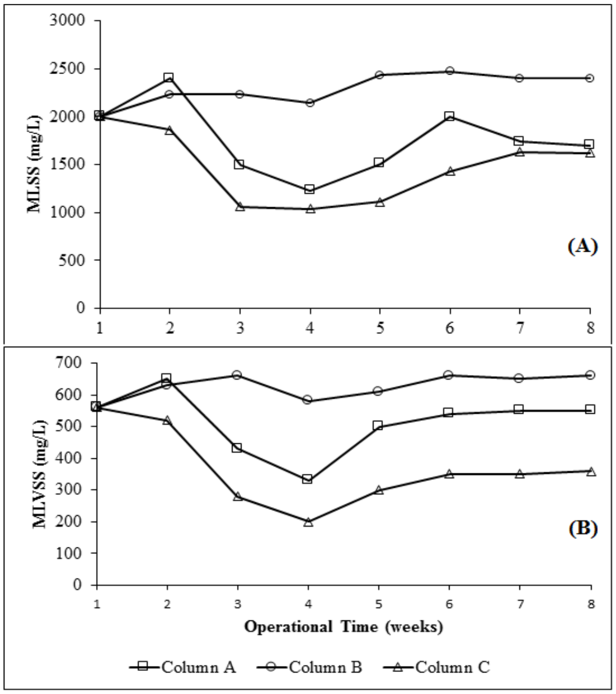

Figure 2: Profile of biomass concentration (A) MLSS (B) MLVSS in all columns

Despite the condition of low DO concentration, Column B was able to retain high biomass concentration compared to Column A and C. As more sludge coagulated to each other, higher settling ability was maintained in Column B. In addition, less sludge washout was observed resulting in higher biomass concentration in the Column. The increase in sludge biomass under the effect of magnetic field was also observed by Łebkowska, Rutkowska-Narożniak (7) and Zaidi, Sohaili (4). However, Column C showed the lowest MLSS and MLVSS throughout the experiment. This may be due to the condition of low oxygen concentration where the mixing of biomass was not sufficient. As a result, less biomass was exposed to the magnetic field, thus no effect of magnetic field was detected.

3.1.2 Settling Velocity and Sludge Volume Index (SVI)

Figure 3 shows the results of settling velocity obtained from all columns. On the average, settling velocities of the magnetically exposed activated sludge in Column B and C were 95±0.7 and 67±1.2 m/h, respectively. Compared to unexposed activated sludge in Column A (53.4 ± 3.8 m/h), these values were greater. As stated by Sears, Alleman (23), changes in settling velocities were likely associated with an increase in the settled sludge density. Here, the difference in settling velocity between magnetically exposed and unexposed activated sludge might have influenced the size and shape of the flocs, possibly due to the applied force of magnetic field (24, 25). In fact, the application of EMF had improved the sedimentation of sludge, owing to the paramagnetic characteristics of iron existed in wastewater (20). Basically, this effect varies with different iron concentrations, magnetic field strength, magnet types as well as Column operation conditions.

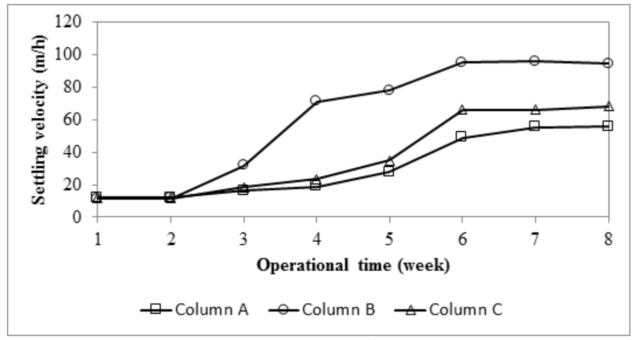

Figure 3: Settling velocity of activated sludge

Sludge volume index is used to indicate the settling ability of sludge. Generally, dense and compact flocs have high settling velocity with low SVI, which shows good settling properties (4). Accordingly, magnetically exposed activated sludge should have high settling velocity and low SVI, unlike unexposed sludge (26, 27). Figure 4 shows the results of settling SVI in the three columns. Fundamentally, the increase in settling velocity would lower the SVI value. It was observed that SVI values for Column B (72.6±1 mL/g) was much lower than for Columns A and C (139.7±2 and 122.3±1 mL/g, respectively). Probably, this could be referred to the effect of magnetic field that might had increased the collision among the particles, which lead to the formation of larger flocs. Since Column B displayed higher MLSS concentration, higher chances of collision occurred, which encouraged the particles to settle rapidly.

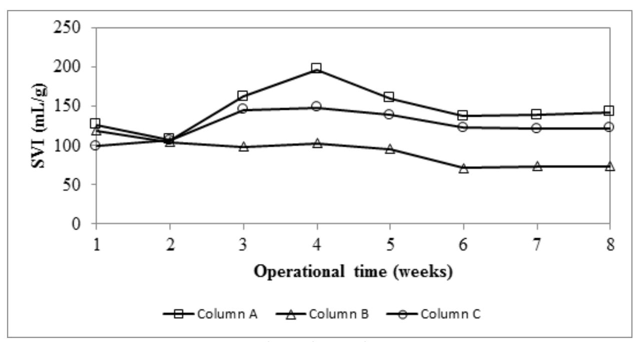

Figure 4: Profile of SVI for all columns

3.2 Removal Performance

3.2.1 Chemical Oxygen Demand (COD)

The profile of COD removal performance is given in Figure 5. It was found that the efficiency of COD removal was similar in all columns, with a slightly higher percentage in Column B. Most of previous studies that applied magnetic field intensity within the range of 5-460 mT illustrated that magnetic field is an intensifying factor for organic substrate degradation (6, 9, 28). In the current study, the EMF intensity was as low as 3 mT, which explains the observed improvement in COD removal. Principally, magnetic field could stimulate the organism biodegradation ability of aerobic bacteria in the activated sludge, probably due to the increase in the concentration of extracellular enzymes distributed on the bacterial surface when exposed to magnetic field (6, 20).

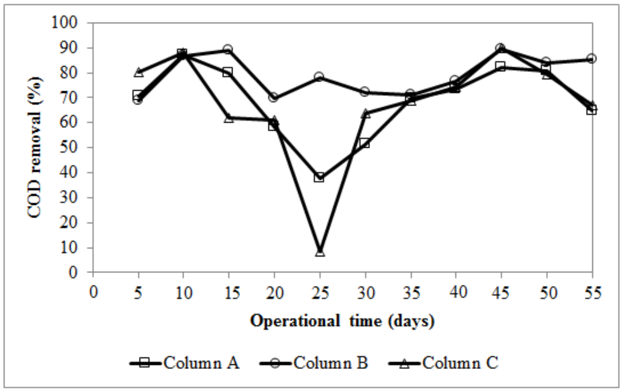

Figure 5: Profile of COD removal performance

At the initial stage of the experiment, COD removal tended to fluctuate due to inconsistent COD influent concentrations that were fed into the systems. On the 25th day of the experiment, COD removal in Column C witnessed a severe drop with only 8.5% of COD was removed. This could be due to the sludge that has been dominated by the proliferation of filamentous microorganisms. At low DO levels, filamentous microorganisms have a greater tolerance compared to floc-forming bacteria. Consequently, filamentous microorganisms could actively proliferate as their relative biomass increases, thus limiting the growth and activity of aerobic microorganisms to biodegrade the COD (29). Apparently, applying EMF with low intensity was not sufficient to enhance the removal of COD under low DO levels. After 35 days, the concentration of COD effluent was almost the same in the control and magnetically exposed columns. However, the COD removal in Column B was always higher than Column A and C, reaching up to 90% of COD removed. Furthermore, the average COD concentration throughout the experimental period for Column A, B and C were 46.4 ± 13, 35.4 ± 9 and 43.7 ± 13 mg/L, respectively.

3.2.2 Ammonia nitrogen

The results of the removal performance of ammonia nitrogen were given in Figure 6. In general, Column B showed higher removal performance compared to Column A and C. During early stage of the experiment, higher removal was observed in Column C, indicating that the system was not in stable condition yet. Starting from day 25, Column B showed higher removal performance compared to Column C until the end of experiment. On average, Column B exhibited the highest ammonia removal (99±1%) followed by Column A (98±1%), while the lowest removal was in Column C (83±9%). Although the Columns were aggravated by low DO condition, Column B was able to maintain higher removal of ammonia. This finding agrees with the phenomenon that the magnetic field has an effect in enhancing the biological activity of ammonium oxidizing bacteria (20), which improved the degradation activity of influent ammonia concentration, resulting in high removal percentage in Column B.

Figure 6(B) shows the concentration of ammonia in the influent and effluent of the three columns. At steady state, the average effluent concentration of Columns A, B and C were 0.6±0.4, 0.4±0.3 and 5.3±0.8 mg/L, respectively. Besides, rapid fluctuations in effluent concentrations were observed in all columns. The obtained results suggested that unstable amount of biomass loss in the effluent could have occurred during the experiment. The losses in biomass could have reduced the presence of aerobic microorganisms responsible in degrading the ammonia, and this clarified the inefficient removal of ammonia occurred in Column C.

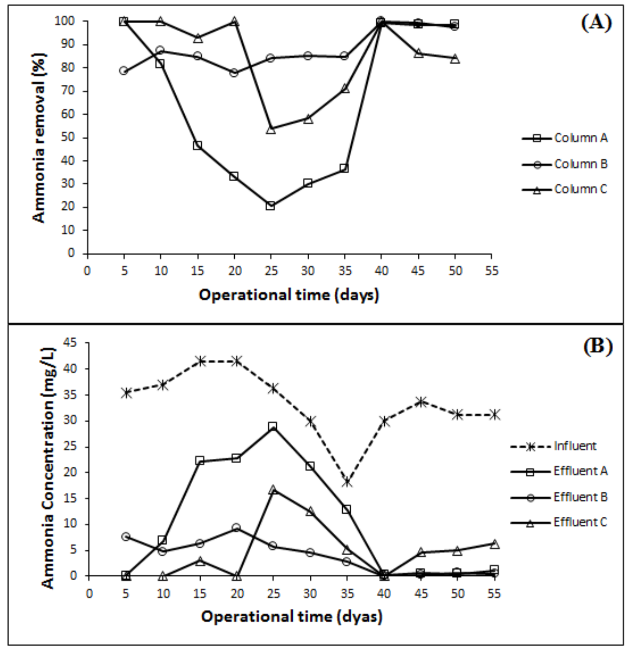

Figure 6: Profile of ammonia removal efficiency (A) and concentration (B) in all columns

3.2.3 Nitrate, nitrite and total nitrogen

The variation of nitrite, nitrate and total nitrogen in the columns are presented in Figure 7, 8 and 9, respectively. Based on Figure 7, the nitrite removal for Column B was high compared to Columns A and C. Moreover, Column B was able to be achieved 100% removal starting from the 45th day until the end of the experiment. On average, the nitrite removal for Column A and Column C were 93.8 ± 9 % and 65.5 ± 5% respectively. A consistent low effluent concentration was indicated in Column A, while severe fluctuations were observed in Columns B and C. In general, the average concentration of effluent nitrite for Column A throughout the experimental period was 0.5±0.7 mg/L while Column C was 3.5±0.6 mg/L.

Theoretically, nitrite is produced through the oxidation of ammonia by *Nitrosomonas* and being removed further by *Nitorbacter* into nitrate (30). In the current study, the low effluent concentration achieved by Column B could be explained by the theories stated by Tomska and Wolny (9), which stated that magnetic field has a potential to enhance the growth and activity of nitrifying bacteria, thus allowing it to undergo the effective nitrification process. Conversely, the efficiency of nitrite removal in Column C was much lower at the end of the experiment. This was most likely because of the low EMF intensity applied, which did not significantly enhance the activity of nitrifying bacteria in the low DO condition. Also, low DO concentration reduced the mixing intensity, which caused the activated sludge to remain statically at the bottom of the glass column. Eventually, this situation resulted in restriction of the movement of sludge perpendicularly towards the magnetic field lines. Consequently, less sludge particles were exposed to the magnetic field, hence, resulted in higher effluent concentration and lower removal percentage.

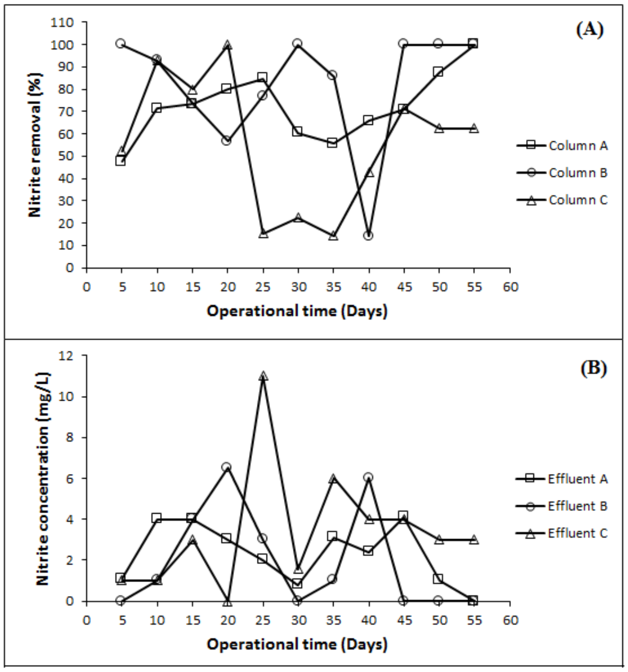

Figure 7: Profile of the nitrite removal performance (A) and concentration (B) in all columns

Essentially, oxidation of nitrite into nitrate requires sufficient source of oxygen supply. However, the current experiment was set in a condition of low oxygen concentration, in order to study the influence of magnetic field to overcome such condition. As a result, this condition affected the oxidation process, causing obvious variations in nitrite removal efficiency in Column C. Apart from that, the inconsistent concentration of nitrite in the influent contributed to the obtained outcome.

The overall results of nitrate removal showed that the effluent released by Column A contained slightly lower nitrates compared to Column C (Figure 8). The production of nitrate was obvious in all columns throughout the experimental period. The average concentration of nitrate produced by Column A was 1.6 ± 0.1 mg/L while Column C was 3.4 ± 0.6 mg/L. Figure 8 shows that the production of nitrate in Column B was dominant over Column A and Column C, which indicates that the denitrification process failed to take place effectively in Column B. Although the system was set at low DO concentration that supposed to enhance the denitrification process, Column B and Column C failed to reach such condition. This could be due to the lack of responsible denitrifying bacteria (i.e. heterotrophic bacteria). As reported by Zaidi, Sohaili (4), the heterotrophic bacteria could be washed-out during decanting phase, hence leaving only a small number of denitrifying bacteria. As a result, inefficient denitrification process occurred in Column B leaving high concentration of oxidized nitrate in the treated effluent.

Total nitrogen fluctuation in the effluent of all columns was observed. This was possibly due to the unstable influent loading of the raw wastewater used in the study. As shown in Figure 9, it can be seen that the average removal of total nitrogen for Column A, B and C was 41.8 ± 7%, 83.8 ± 1% and 63 ± 1.7%, respectively. The higher treatment performance indicated by Column B could be owing to the present of the Nitrosomonas and Nitrobacter bacteria, which became more active under the effect of the EMF and exhibited strong nitrogen oxidizing activity (8, 20). Moreover, the steady state of total nitrogen concentration was achieved after 40 days for all columns.

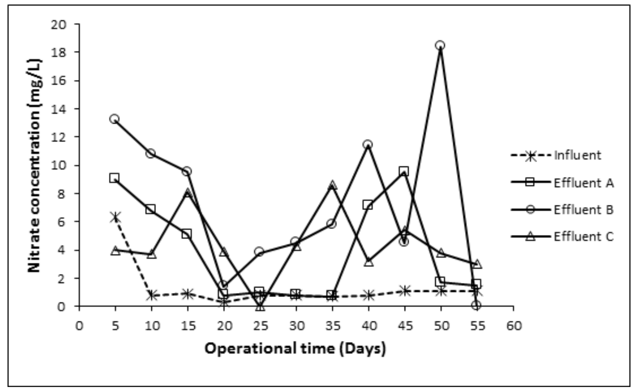

Figure 8: Influent-effluent nitrate concentration in Column A, Column B and Column C

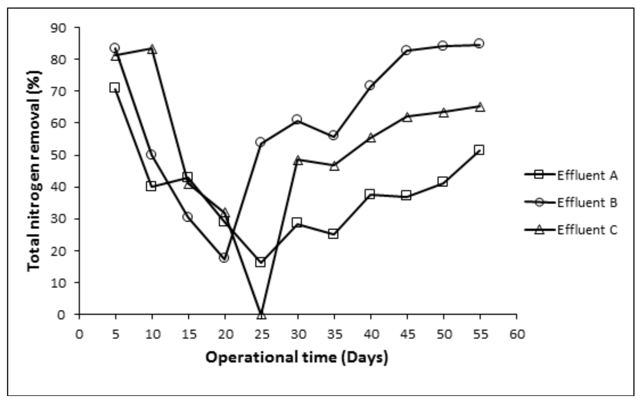

Figure 9: Removal performance of total nitrogen in all columns

4 Conclusion

The current work studied the enhancement of AS process under low DO concentrations of 1 and 2 mg/L, through the application of EMF with intensity of 3mT. It was illustrated that exposure of AS to EMF significantly improved the accumulation of biomass concentration. In addition, the highest removal performance, in terms of COD, ammonia, nitrite and total nitrogen, was obvious in the column exposed to EMF with DO concentration of 2 mg/L. The only parameter that EMF did not improve its removal is nitrate, due to the lack of nitrifying bacteria under low DO condition. Finally, this study proved that EMF could enhance the settleability of the AS in the treatment system.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses.

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