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Enhanced Biomass Properties In Sludge Bulking: Impact of Static Magnetic Field

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Abstract. Occurrence of sludge bulking with regard to prolong sludge age declines the removal performances attributable to the failure of aggregation by the floc-formers and insufficient adhesion among cells' surfaces. Approach of sufficiently minimizing the sludge age had been taken most of the times. This approach, however, eliminated the floc-formers although it was found to inhibit the bulking. The aim of the present study, therefore, is to investigate the potential of magnetic field application as an alternative approach to control the sludge bulking. Two sequencing batch reactors, Reactor A (SBR_A) and Reactor B (SBR_B), were operated in long sludge age to induce the bulking. SBR_A was subjected to 88.0 mT magnetic field intensity while SBR_B served as a control system. The findings showed that the magnetic field was able to enhance the biomass properties including the aggregation ability, relative hydrophobicity and maintain significant negative surface charge under an adverse effect of long sludge age thus led to more stable flocs been formed. This had resulted with consistent high removal of SBR_A compared to SBR_B. Consequently, this approach minimizes the occurrence of sludge bulking.

Keywords: Magnetic field; Sludge bulking; Biomass properties; Removal performances

1. Introduction

Sludge age is an important factor that provides control over sludge activity upon biomass properties. Optimum sludge age allows efficient aggregation, which results in stability of floc formation thus, lead to high removal performances. Long sludge age has been reported in inducing the growth of filamentous microorganisms such as *Nocardioforms* and *Microthrix parvicella* [1] [2]. Sludge that been retained too long in the clarifiers can become septic, lose its activity thus deplete the necessary dissolved oxygen in the reactor [3]. This occurrence favors the growth of filamentous microorganisms hence, causing sludge bulking.

Approach of minimizing the sludge age had been taken commonly to overcome the bulking issue [1] [4]. By reducing the sludge age, food-to-microorganisms (F/M) fed ratio is increase. This condition minimizes the risk of sludge bulking occurrences by inhibiting the growth of filamentous microorganisms [1] [2]. However, it appears that the approach is not only eliminating the filamentous microorganisms, but it also eliminates the nitrifying bacteria [1] [3]. This is because the growth rate of nitrifiers is slow compared to the other heterotrophs (BOD-removing organisms) or even filamentous microorganisms. These organisms require longer sludge age in order to perform the nitrification process. Hence, by shortening the sludge age, deterioration of the nitrification efficiency will eventually occur. It is then crucial to find other potential method to control the bulking occurrence.

Magnetic field has been reported to significantly influence the bacterial activity in heterogeneous sewage, resulted to the significant performances of biodegradations. Under low magnetic field intensity, the biomass growth and dehydrogenase activity was positively affected thus reduced the COD by 26% [5]. Weak magnetic field of 17.8 mT was also evidenced to cause bacterial growth to increase up to 44% [6]. Such enhancement on biomass activity resulted to the increased of substrate removal rate. According to [7], magnetic field plays its role by manipulating the positive and negative charges of the bacterial cells. The charges are well separated and easily aligned in accordance to the direction of the magnetic field. This occurrence strengthens the electrostatic force and polymeric interaction that can further enhanced the cell's adhesion. With this enhancement, the surface hydrophobicity of the biomass can also increase followed by the increase in the removal performances.

Therefore, the aim of this work is to investigate the feasibility of static magnetic field application on the biomass that been induced under long sludge age which prominently as a common condition affecting sludge bulking occurrence. The influences of magnetic field on the biomass properties as well as removal performances of the treatment process were monitored using controlled laboratory scale of SBR systems.

2. Materials and Methods

2.1. Wastewater and biomass collection

Raw municipal wastewater sampled from the Indah Water Konsortium (IWK) sewage treatment plant was used in this study. The biomass used in this study was also collected from the same treatment plant. The purpose of using the same wastewater and biomass samples originated from the same treatment plant helps in fastening the acclimatization process. The biomass were sampled from aeration tank and sieved with a mesh of 1.0 mm to remove large debris and inert impurities.

2.2. Experimental setup and operational conditions

Two lab-scale sequencing batch reactors - Reactor A (SBR_A) and Reactor B (SBR_B) were designed with a working volume of 6 L. SBR_A was equipped with the magnetic device while SBR_B acted as a control system. The magnetic device that attached to the SBR_A comprised series of permanent magnets that are arranged in an alternate order. The applied magnetic field was at intensity of about 88.0 mT. Gauss meter was used to check the consistency of magnetization for every 30 minutes.

During the start-up period, 3 L of sludge and 3 L of wastewater were added into the reactor system making the final volume of 6 L with a total sludge biomass concentration of 5.6 g/L. SBR_A and SBR_B were operated in parallel with hydraulic retention time (HRT) of 8-h in 3 successive cycles. Each cycle comprised of 10 min filling, 380 min reaction, 80 min settling and 10 min decanting. The volumetric exchange rate (VER) was fixed at 50%. The temperature of the systems was constant at 25°C while the pH throughout the experiments was between 6.0 and 8.0. In this study, the sludge age was set longer at about 20 days in order to induce the sludge bulking. Withdrawal of certain amount of MLSS was conducted at the end of aeration phase in order to set the sludge age for about 20 days.

2.3. Analytical methods
For the determination of biomass characteristics, the samples were analyzed for biomass concentration, aggregation, relative hydrophobicity and surface charge. In this study, MLSS and MLVSS were conducted based on [8] - Method No. 2540D and 2540E, respectively. Aggregation was evaluated in terms of turbidity measurement [9] [10]. Relative hydrophobicity of the biomass was measured as adherence to hydrocarbons [11] while surface charge of the biomass was determined by colloidal titration [12]. For the removal performances, chemical oxygen demand (COD) and phosphorus parameters were conducted based on Standard Method [8].

3. Results and Discussions

3.1. Effect of magnetic field on aggregation of the biomass under long sludge age
Occurrence of aggregation is depends on the collision frequency, which is governed by the degree of particle destabilization achieved. High percentage of aggregation suggests that the flocs are easy to form and significantly favors coagulation. Aggregation is an irreversible process and the formed flocs are hard to deteriorate [13]. This suggesting that good aggregation may correlate to the good adhesion capability measured by particles' surface properties. Figure 1 shows the profile of aggregation ability of the biomass in both reactors.

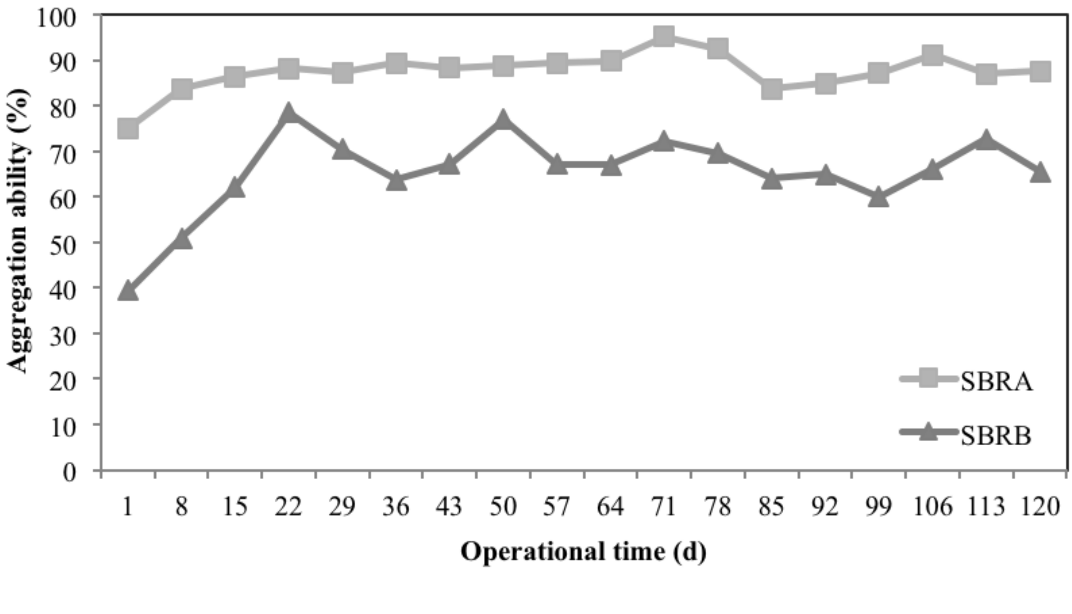

Figure 1. Profile of aggregation ability of the biomass in both reactors

Biomass in SBR_A showed high aggregation with the range of 75.0 – 95.2% while biomass in SBR_B possessed mostly medium aggregation with average of 65.5%. There were obvious differences between biomass in these two reactors. The exposure of magnetic field may contribute to the enlargement of the floc size in SBR_A due to the adherence between flocs as the magnetic forces presence between them [13] [14].

Furthermore, magnetically exposed biomass in SBR_A would hold high densities and sustained the attraction of magnetic forces. This can explain on biomass in SBR_A showed better aggregation throughout the process. The high aggregation observed in SBR_A was also correlated with the high biomass concentration shown in Figure 2. The presence of more cell biomass increases the collision among the cells and cause more aggregation to occur [15]. This suggests that the magnetic field accommodated in SBR_A do have significant effect in increasing the cell growth of the biomass [5] [16].

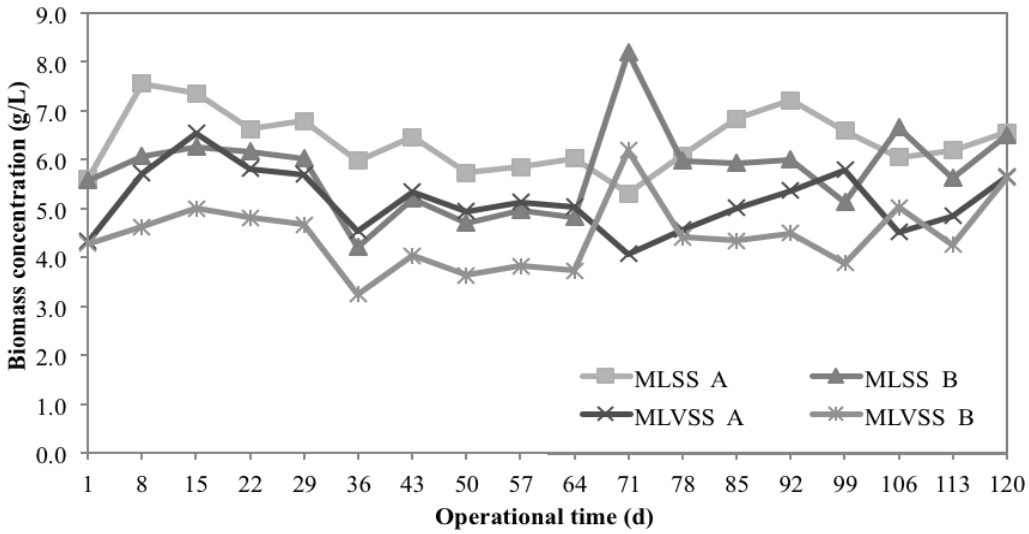

Figure 2. Profile of biomass concentration in both reactors

3.2. Effect of magnetic field on surface charge and hydrophobicity of the biomass under long sludge age

Hydrophobicity and surface charge were the sum effect of the exopolymer interactions. According to [17], the surface properties measured by the relative hydrophobicity and surface charge corresponded significantly to the formation and stability of microbial aggregates. Figure 3 shows the changes in relative hydrophobicity and surface charge throughout the experiment.

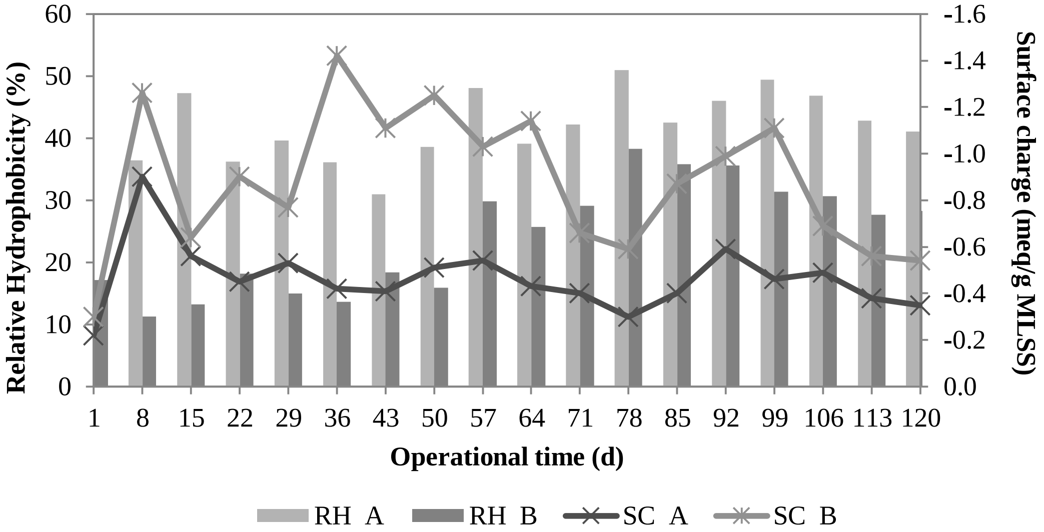

Figure 3. Profile of relative hydrophobicity and surface charge of biomass throughout the experiment

Based on the figure, a strong inverse correlation was observed between the surface charge and sludge hydrophobicity. High sludge hydrophobicity and less negative surface charge give an indication of good settling property of the biomass [18] [19]. The overall sludge hydrophobicity for SBR_A varied between 31% and 51%, with an average value of approximately 42%. The percentage was higher than the sludge in SBR_B, which it is vary between 11% and 38%, with an average value of 24%. [20] observed a strong correlation between the hydrophobicity of cells and their degree of attachment to the flocs. However, the current results presented in this study were not consistent with the findings of the previous research. The obtained relative hydrophobicity was variable and even high in SBR_A.

According to [17], high value of hydrophobicity of the cell surfaces would promote cell-to-cell interaction and further serves as inducing cell force for aggregating out of hydrophilic liquid phase. This is the reason of high relative hydrophobicity indicated by sludge in SBR_A possessed good aggregation and good settlement index compared to sludge in SBR_B. This is also suggesting that magnetic field do have a potential effect in enhancing the interaction that could further increase the hydrophobicity. According to [7], magnetic field plays its role by manipulating the positive and negative charges of the cells. As a result, the electrostatic force and cell-to-cell interaction strengthened, hence promote cell's adhesion. Consequently resulted in high hydrophobicity of the biomass.

The overall floc structures of the biomass were negatively charged due to the result of physico-chemical interactions between bacteria, inorganic particles, extracellular polymers and multivalent cations [21]. Alternatively, magnetic field exposure gives the influence of positive and negative charges that can strongly be absorbed on floc particles. Therefore, the deposition process can result in charge neutralization or even charge reversal. Exposure of magnetic field induces the biomass flocs adherence thus bring a variation in surface charge. The statement supported the findings obtained in this study. The average surface charge of the magnetically exposed biomass in SBR_A was -0.46 meq/g MLSS while -0.88 meq/g MLSS for unexposed biomass in SBR_B. The results showed that the surface charge of biomass in SBR_A which been exposed by magnetic field was twice less than the biomass in SBR_B.

Based on Figure 3, the changing pattern in SBR_A showed decrease surface charge profile with the value at the end of experiment was -0.35 meq/g MLSS. Throughout the experiment, sludge in both reactors showed increase and decrease of the surface charge values. However, magnetically exposed biomass in SBR_A was more successful in decreasing the negative surface charge values compared to biomass in SBR_B. Based on DLVO theory, a decrease in surface charge could results in a decrease of repulsive electrostatic interactions thus further enhance flocculation of the fine flocs [17] [18].

3.3. Effect of magnetic field on COD removal performances under long sludge age

Profile for COD removal performances for both reactors is given in Figure 4. SBR_A showed consistent COD degradation performance with an average removal of 87% compared to SBR_B with average removal of 67%. Previous works using magnetic field in the range of 5 to 460 mT showed that magnetic field is an intensifying factor for organic substrate degradation [22] [23]. The evidences suggested that the magnetic field could increase the organism biodegradation ability of aerobic bacteria from the biomass. This was due to the increase in extracellular enzymes distributed on the bacterial surface when magnetic field was used [7] [14] [22].

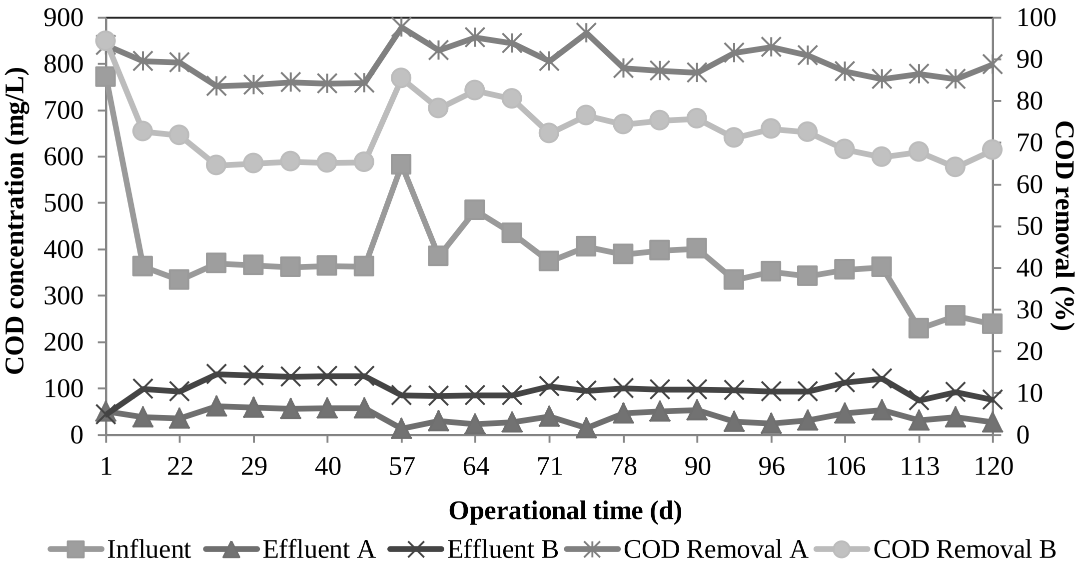

Figure 4. Removal performances of COD for both reactors throughout the experiment

Figure 4 also showed that SBR_A and SBR_B were having maximum COD removal of about 98% and 85%, respectively at day-57. The maximum degradation occurred might be due to the increase of influent COD of about 582 mg/L on the exact day. Such high influent concentration may caused high substrate uptake rate in both systems thus, enable the performance to reach maximum degradation process. However, on the day onwards until the end of experiment, a surge drop of COD removal was observed in both reactors. The COD removal for SBR_A reduced from 98% (day-57) to 89% (day-120) while for SBR_B, the removal was reduced from 85% to 68%. The drop could be due to the sludge washout into the effluent. The formed flocs may not be so intact and could easily detach within each other. With regard to the exposure of magnetic field, the drop of COD removal in SBR_A was minimum (i.e. 9%) compared to the SBR_B (i.e. 17%). This could be due to the existence of magnetic memory of the exposed biomass [24]. During the exposure, the sludge would have an opportunity to retain the effect of magnetization and the effect could become stronger as the sludge being repeatedly exposed during the experiment. Hence, under adverse circumstances, the retained magnetic field in the exposed biomass can still maintained the floc formation, inhibited more sludge washed-out thus, consistently enhance the removal.

3.4. Effect of magnetic field on phosphorus removal under long sludge age

Phosphorus from wastewater can be presented as orthophosphates, condensed inorganic phosphates and organophosphates. In this study, orthophosphates represented the phosphorus removal. The variation of orthophosphates in both reactors was shown in Figure 5. Based on the figure, the effluent orthophosphate concentration for SBR_A was lower than in SBR_B. During initial operational day, both reactors showed about the same effluent concentration of 9 mg/L. At day-22, both SBR_A and SBR_B showed an increase in the effluent concentration at about 13 mg/L and 19 mg/L, respectively. This could be due to the increase in the influent concentration, which was about 26 mg/L.

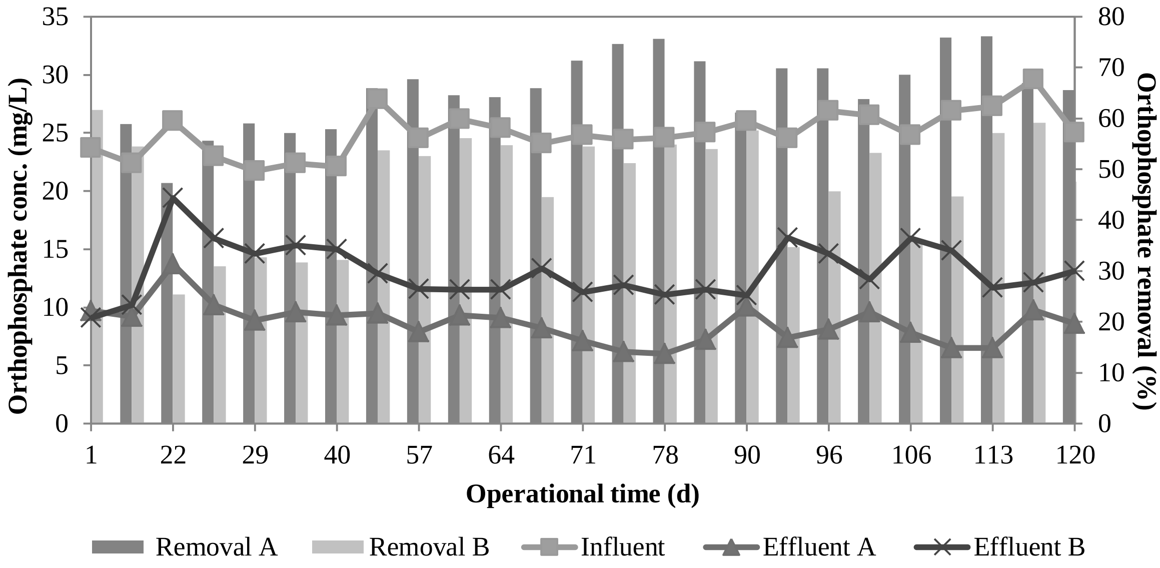

Figure 5. Removal performances of orthophosphate for both reactors throughout the experiment

Prolonged operational time, the effluent orthophosphate concentration in SBR_A showed gradual decrease with average removal efficiency of about 71%. In contrast, the effluent concentration in SBR_B showed several fluctuations especially during the end of the experiment thus resulted in low removal efficiency of only 49%. These observation that showed better removal performance of SBR_A compared to SBR_B can be reasoned due to the probable effect exhibited by the magnetic field in enhancing the activity of biomass including phosphorus-accumulating organisms (PAOs). The magnetic field manages to influence the enzymatic and metabolic activity of the cells [14]. According to [25], electric/magnetic field was able to increase the crude enzyme activities and cell quantities of the heterotrophic bacteria. Such increments were the main reasons for the enhancement in various removal performances. With such evidences, there could be a great potential for PAOs to be positively influenced by the magnetic field thus accelerated the orthophosphate removal in SBR_A.

4. Conclusions

Until today, there is lack of information on the effect of magnetic field on sludge bulking. Under the effect of magnetic field, the biomass properties in SBR_A were enhanced thus resulted to greater removal performances compared to the control reactor (SBR_B). Biomass in SBR_A postulated high aggregation of 95% compared to 65% as in SBR_B. In terms of surface charge, biomass in SBR_A showed less negative charged compared to biomass in SBR_B. These observations imply that the magnetic field was able to enhance the ability of the biomass to form stable flocs under the probable adverse effect of long sludge age.

With such improvement of the biomass, SBR_A showed consistently high COD removal of average 87% compared to SBR_B of 67%. These observations imply that the magnetic field was able to enhance the biodegradation ability of aerobic bacteria even under long period of sludge age. Overall, under the sludge bulking, the use of magnetic field stand a great chance in maintaining high removal performances.

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