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Full Length Research Paper

Removal of phosphate from municipal wastewater using anaerobic /aerobic modified SBR reactor

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Abstract

Phosphorous is the main and key nutrient in freshwater systems which is stimulative to algae, aquatic plants and photosynthetic microorganisms' growth and should be removed to prevent eutrophication phenomenon. In this study efficiency of removal of the COD (Chemical Oxygen Demand) and the TP (Total phosphate) was investigated using a new anaerobic-aerobic/anoxic modified SBR reactor. An anaerobic-aerobic/anoxic modified SBR reactor was used in 4 different operating phases in time range of 3 to 8 hours in order to reach the best COD and TP removal conditions. The input phosphate concentration and input COD were varied from 4 mg/L to 60 mg/L and from 250 mg/L to 1500 mg/L respectively. The phases 3 and 4 were chosen as the best phases with 91.9% and 84.4% in phase 3 for COD and TP removal efficiencies respectively and also 92.7% and 86.9% for COD and TP removal efficiencies in phase 4. The retention time of phase 4 was included alternatively 225 minutes aeration, 165 minutes mixing and 90 minutes sedimentation. This new reactor has several advantages including high efficiency in removal of organic materials and phosphate, continuity in input flow, the low space and volume occupation.

Keywords: Modified SBR reactor, phosphate, Anaerobic, Aerobic.

INTRODUCTION

Because of being abundantly available, surface water supplies are considered as reliable water supplies in many parts of the world (Zhang and Angelidaki, 2012). Extreme increase in the amounts of nutrients (Nitrogen and phosphorous) in the environment of surface water supplies by discharging the wastewater of human activities (excretion materials, industrial and commercial supplies, detergents, and cleaner products), causes varied environmental problems such as disorder in human health, negative effects on global cycle of nutrients and eutrophication (Tait et al., 2013; Seviour et al., 2003); which eutrophication itself causes problems including decrease in the oxygen level of the water, aquatic species death, reducing the potable water's quality etc. and it consequently leads to damages such as ecosystem destruction, reduction of biodiversity and finally economic damages (Yamada et al., 2012) . Most of the scientists believe that phosphorous is the main and key limited nutrient in freshwater systems which is stimulative to algae, aquatic plants and photosynthetic microorganisms' growth and should be removed to prevent eutrophication phenomenon (Olli et al., 2009; Kney et al., 2004) . The amount of phosphate in municipal wastewater with average contamination loading is between 10 to 15 mg/L (Huang et al., 2008) . Eutrophication is directly related to human activities such as releasing the municipal and rural wastewater in the surface water supplies, industrial wastewater and also urban and agricultural streams contaminated with nutrients and organic materials (Yamada et al., 2012) .

Considering the freshwater supplies shortage for different usages, for instance drinking, agriculture, entertainment and industry, increases the importance of water supplies to health and therefore it seems very essential to control the discharge of phosphate from manmade supplies to surface water supplies such as lakes, rivers, streams, seas etc. With increasing level of

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phosphorous in surface water and eutrophication problem in the recent decade, the technological methods of phosphorous removal have been developed extendedly (Morse et al., 1998).

The common technologies for phosphorous removal are classified in 3 main types; physical (sedimentation, filtration, adsorption, ion exchange, electrodialysis, reverse osmosis), chemical (chemical precipitation with iron, aluminum, calcium or lime salts), and biological ones which depend on biologic biomass type (bacteria, algae, plants). Physical and chemical phosphorous removal processes don't have stable applications and also are very expensive, but biologic ones are highly efficient and more economic processes (Huang et al., 2008) .

The sequencing batch reactors (SBR) process have been used abundantly to remove the COD and phosphate from wastewater and another reason of its widespread usage is low financial and operational costs rather than other common nutrient removal processes (Kargi and Uygur, 2003;2004) .Aerobic, anoxic and anaerobic cycles and organic materials are required for biological nutrient removal (BNR) and all of them are available in SBR process. This process type has the advantage of better management of mixed liquid, oxygen amount and aerobic/ anoxic / anaerobic cycles (Dubber and Gray, 2011; Akhbari et al., 2011) . The Enhanced biological phosphorous removal (EBPR) is accomplished by active sludge return from anaerobic phase to aerobic phase and also continuous influx of the wastewater to anaerobic phase (Mino et al., 1998). EBPR is considered as the most economic and appropriate method (no need to chemical precipitation) to remove phosphorous from wastewater. An EBPR process requires anaerobic, aerobic/ anoxic conditions and it removes phosphorous from wastewater by using polyphosphate accumulating organisms (PAOs) in alternative aerobic and anaerobic conditions. Thus in this study, anaerobic condition was prepared with separation of this sector from the reactor and the aerobic/ anoxic condition was prepared in other side of the reactor using time cycles.

Several studies have been done on removal of nutrients, but there have been few studies on rector systems with alternative anaerobic/ anoxic and aerobic phases (Sponza and Atalay, 2005). A new modified SBR reactor with continuous input and discontinuous output was used in this study which had the anaerobic-anoxic/ aerobic condition. This system had a stable function in the COD and TP removal. This type of reactor is of important advantages such as high efficiency in organic materials and phosphate removal, having continuous input flow and low area and volume occupation.

MATERIALS AND METHODS

Operating phases

Four different phases was used in this study which phases 1 and 2 was used without mixed cycles, but phases 3 and 4 included mixed cycles. The schematic of operating phases with their details are depicted in figure 1. The total time of phases 1, 2, 3, and 4 was 180 min, 240 min, 360 min, and 480 min respectively.

Synthetic wastewater

To have a better control on the reactor system and also to prevent fluctuation in amounts of the COD and phosphate in input wastewater, synthetic wastewater was used (Rahimi et al., 2011). All the materials used for making synthetic wastewater and their amounts are brought in Table 1. Tap water was used to make synthetic waste water and pH was about 7.4 in all the study time.

Reactor system

The reactor used in this study was a modified form of SBR reactor which had a continuous influx of synthetic wastewater and discontinuous output of treated wastewater. The reactor was made from Plexiglas sheets and included anaerobic and anoxic/aerobic parts. Anaerobic part was located in the beginning of wastewater treatment and the anaerobic condition was held constantly in it. The anoxic/ aerobic part was located in a tank after the anaerobic part and was controlled by electric timer and aquarium air pump; aerating was done by an aquarium air pump attached with an air stone in the bottom of anoxic/ aerobic part. The total volume of the reactor was 9 L and operating volume was varied from 5 liter to 7 liter for different phases. Phase 1 had the lowest operating volume, while phase 4 had the highest value of operating volume. The internal diameter of the reactor was 15 cm and its height was about 40 cm. The schematic of the reactor system and its belonging is shown in figure 2.

Reactor operating

To have a better control on the rector (aerating, mixing, and discharge), 3 electric timers (theben-germany) were used and a peristaltic pump (Ismatec-Germany) was used for entering the wastewater and finally an electric valve (2&2-china) was used to discharge it. To determine the amount of dissolved oxygen (DO), a DO meter (HACH HQd Field case-USA) was used and also a pH meter (metrohm-826-Switzerland) was used to determine pH values. The DO value of aerobic cycle was about 2.5 mg/L to 3.5 mg/L and this parameter for anoxic cycle was about 0 to 0.2 mg/L and all the experiments were done at the room temperature.

The required sludge for microbial inoculums of the reactor was prepared from the sludge return line of the

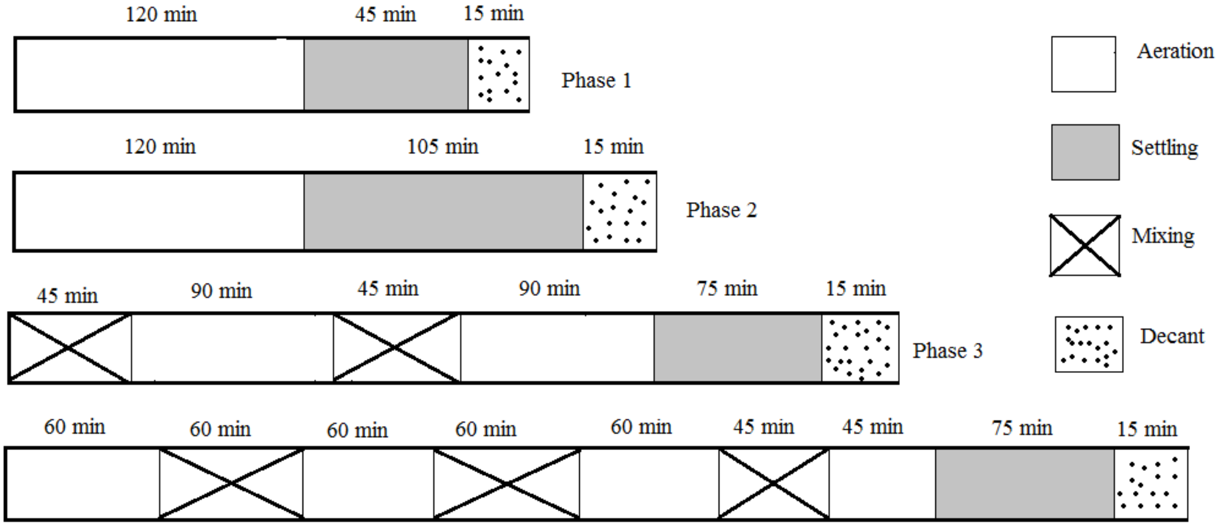

Figure 1. The schematic of operating phases in the reactor

Table 1. Type and amount of materials used in synthetic wastewater

Material Type	concentration (mg/L)
Glucose	0.33-0.97
Sucrose	0.12-0.36
sodium acetate	0.12-0.36
(KH_2PO_4)	0.11-0.84
Ammonium chloride (NH_4Cl)	0.14-0.388

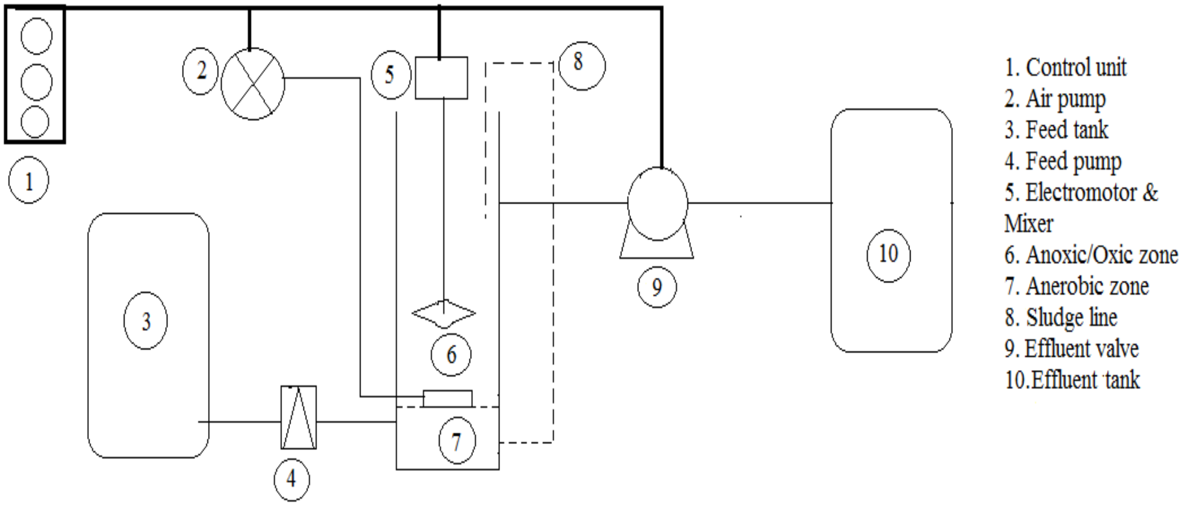

Figure 2. The schematic of modified anaerobic-aerobic SBR reactor system

municipal wastewater treatment plant of Shiraz – Iran. In phase 2, 200 – 300 mL sludge of anaerobic zone was transferred daily to anoxic/ aerobic zone which it was always transferred during the aerating phase. The reactor operating time was 100 days totally which 15 days was spent to make the system ready to use.

EXPERIMENT METHODS

Measuring the total phosphorous (TP) of the input and output wastewater was performed by spectrophotometer (DR-5000 HACH-Germany) and measuring the COD was done by closed reflux colorimetric method in the standard methods book (APHAA , 1998). To determine the TP value, the orthophosphate present in the sample was reacted by molybdate in an acidic media to prepare a phosphate/molybdate complex; then this complex was reduced by ascorbic acid and the blue color of molybdenum was appeared which the intensity of the color determines the orthophosphate in the sample and the sample was read in the 880 nm wave length in the spectrophotometer (Rahimi et al., 2011).

RESULTS

COD removal efficiency

During the study time, the anaerobic-anoxic/ aerobic reactor showed a high efficiency in input COD with varied concentrations from 500 mg/L to 1500 mg/L which this range of COD represents wastewater with average to drastic contamination intensity [Metcalf, 2003]. The mean percentage of COD removal efficiency for phases 1 to 4 was 92, 91.1, 91.9, and 92.7 respectively and the mean percentage of all the phases together was 91.9. Hence it can be said confidently that the COD removal efficiency is high and completely acceptable in all the phases. The amount of input COD for phases 1, 2, and 3 was 530 ± 10 mg/L, 550 ± 10 mg/L, and 550 ± 10 mg/L respectively and for phase 4 was 550 ± 10 mg/L, 725±10 mg/L, 1000 mg/L, and 1500 mg/L respectively. Similarly, this amount for output COD in phases 1, 2 and 3 were 35±15, 40±10 and 45±10 respectively; these amounts in phase 4 were 45±0, 50±10, 65±10 and 105±10 respectively. The COD removal efficiencies and also the mean COD removal efficiencies are brought in figure 3 and table 2 respectively.

Total phosphorous (TP) removal efficiency

The figure 4 shows the TP removal efficiency and the mean TP removal efficiency for all the concentrations are reported in Table 2 in details. Anaerobic – anoxic/aerobic reactor showed high efficiency in total phosphorous (TP) removal. The amounts of input TP for phase 1 was 4 mg/L PO_4^{3-} and 15.8±0.4 mg/L PO_4^{3-}, for phase 2 was 16±0.5 mg/L PO_4^{3-} and 8.5 mg/L PO_4^{3-}, for phase 3 was 8±0.5 mg/L PO_4^{3-}, and for phase 4 was 8.5 mg/L PO_4^{3-} , 16.4±0.2 mg/L PO_4^{3-}, 30.5±0.4 mg/L PO_4^{3-}, 45 mg/L PO_4^{3-}, and finally 60 mg/L PO_4^{3-}. The total average of TP removal for phases 1, 2, 3, and 4 was 48.11%, 84.9%, 84.4%, and 86.9% respectively.

The dissolved oxygen (DO) variations are shown in figure 5. Repetitive cycles led to repetitive dissolved oxygen (DO) concentrations. The DO level in end of any aeration cycle was at highest and in the settling/mixing cycle was at lowest level.

Effect of input COD/P ratio

Input COD/P ratio variations were investigated in phase 4. Phase 4 was consisted of three 8-hour cycles each day (total time of phase 4 was 480 min) which one cycle in each day was studied to investigate COD/P ratio. The COD concentration reduced from 1500 mg/L to 250 mg/L and the TP concentration was held constant in about 60 mg/L and COD and TP removal efficiencies were investigated. The COD/P ratio was 25 for input COD concentration of 1500 mg/L which was its highest value and also the lowest COD/P ratio was 4.1 which belonged to input COD concentration of 250 mg/L. The COD removal efficiency was almost constant during the COD ratio survey period. The TP removal efficiency was relatively constant until the input COD concentration of 500 mg/L, but it experienced a sudden fall from 78% to 72% in input COD concentration of 250 mg/L. The COD ratio variation versus COD and TP removal efficiencies are shown in figure 6.

Effect of sludge transfer from anaerobic zone to aerobic zone

The sludge transfer from anaerobic zone to aerobic zone phase 2 was surveyed in this reactor to study the TP output value versus its input value which the TP input value was about 16 mg/L in whole the study (figure 7). A high difference in output TP concentration was seen in presence and absence of sludge transfer; when the sludge transfer was done, output TP concentration was about 1.8-2 mg/L, but it was about 14 mg/L when the sludge transfer was not done and therefore phase 2 was accomplished under sludge transfer from anaerobic zone to aerobic zone.

DISCUSSION AND CONCLUSIONS

According to figure 3, with variation of input COD from 250 mg/L to 1500 mg/L, COD removal efficiency remains in the range of 80% to 95% in all the phases. The input COD value was increased suddenly and in high orders in phase 4, but no significant variation was seen in COD removal efficiency. For example, when the input COD was increased 500 mg/L, from 1000 mg/L to 1500 mg/L, despite our expectation the COD removal efficiency didn’t change considerably and this shows high flexibility of this reactor versus the COD loading fluctuations in the studied COD range. wang et al. 2009 in studying of phosphorous and nitrogen removal in a SBR reactor figured out that their SBR reactor have a good efficiency in high TOC loading shock, but with decrease in loading, the removal efficiency was not appropriate. In our modified SBR reactor with increase or decrease in loading, loading shock or normal loading, COD removal efficiency was proper (Wang et al., 2009) . It cannot be

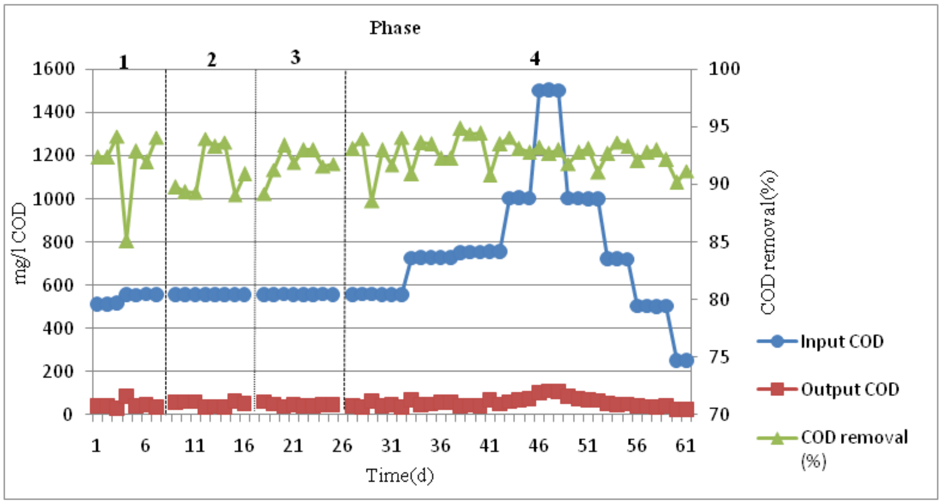

Figure 3. The COD removal efficiencies for different phases in the reactor

Table 2. COD and TP removal efficiencies for all the phases

Phase	The mean TP removal efficiency	The mean COD removal efficiency
1	Removal efficiency for 4 mg/L PO_4^{3-}: 43.4% Efficiency for 16 mg/L PO_4^{3-}: 51.6%	Removal efficiency for COD input concentration of 530±10 mg/L: 92%
2	Removal efficiency for 16 mg/L PO_4^{3-}: 75% Efficiency for 8 mg/L PO_4^{3-}: 84.4%	Removal efficiency for COD input concentration of 550±10 mg/L: 91.18%
3	Removal efficiency for 8 mg/L PO_4^{3-}: 84.4%	Removal efficiency for COD input concentration of 550±10 mg/L: 91.9%
4	Removal efficiency for 8 mg/L PO_4^{3-}: 84% Removal efficiency for 16mg/L PO_4^{3-}: 90.72% Removal efficiency for 30 mg/L PO_4^{3-}: 93.44% Removal efficiency for 45 mg/L PO_4^{3-}: 88.2% Removal efficiency for 60 mg/L PO_4^{3-}: 84.2 %	Removal efficiency for COD input concentration of 555 mg/L: 92.4% Removal efficiency for COD input concentration of 725±25 mg/L: 93.11% Removal efficiency for COD input concentration of 1000 mg/L: 92.4% Removal efficiency for COD input concentration of 1500mg/L: 92.95% Removal efficiency for COD input concentration of

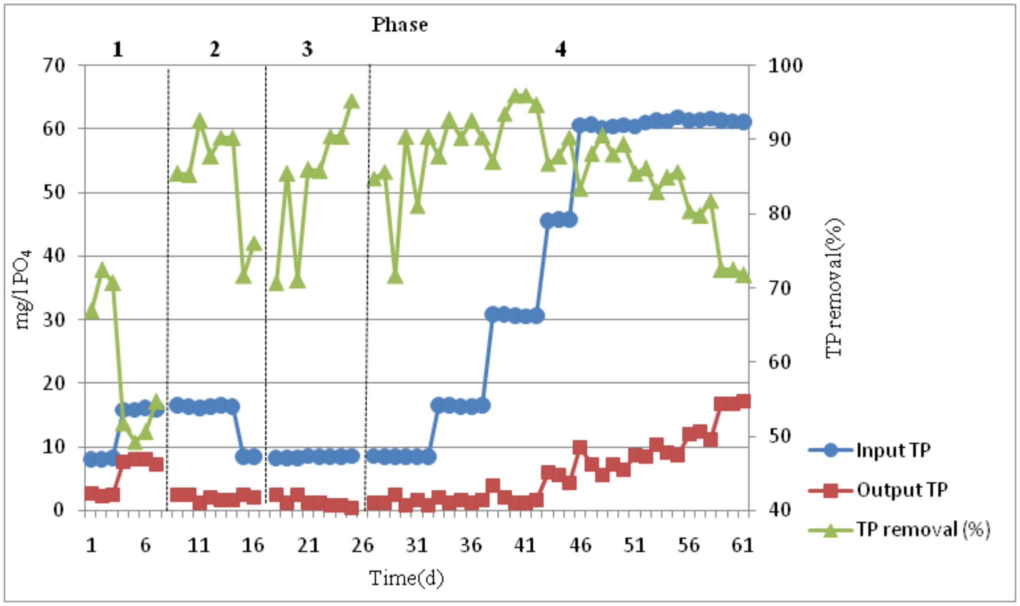

Figure 4. The TP removal efficiency in different operating phases

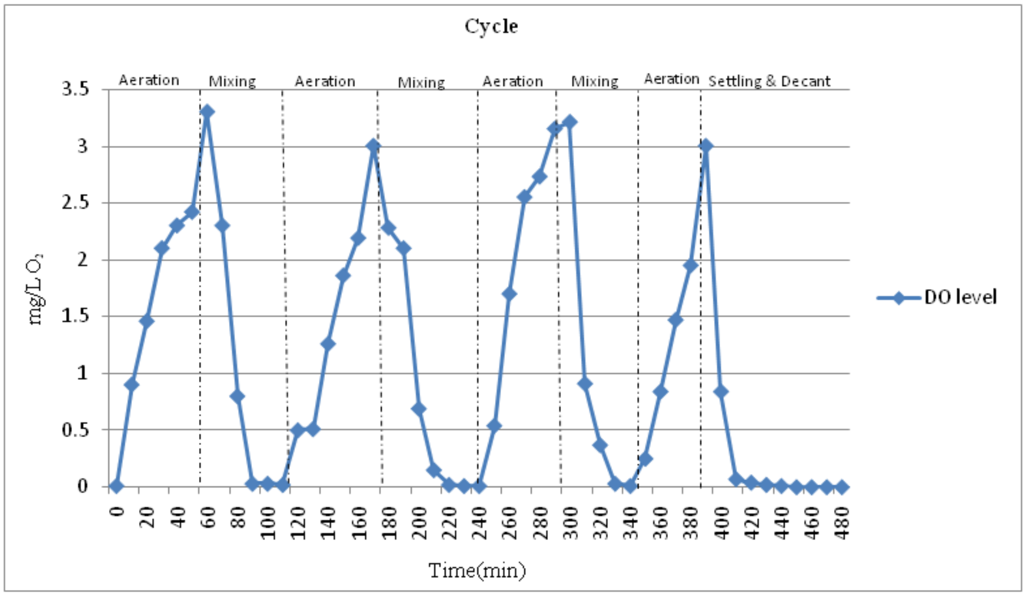

Figure 5. The dissolved oxygen (DO) variations versus time in phase 4

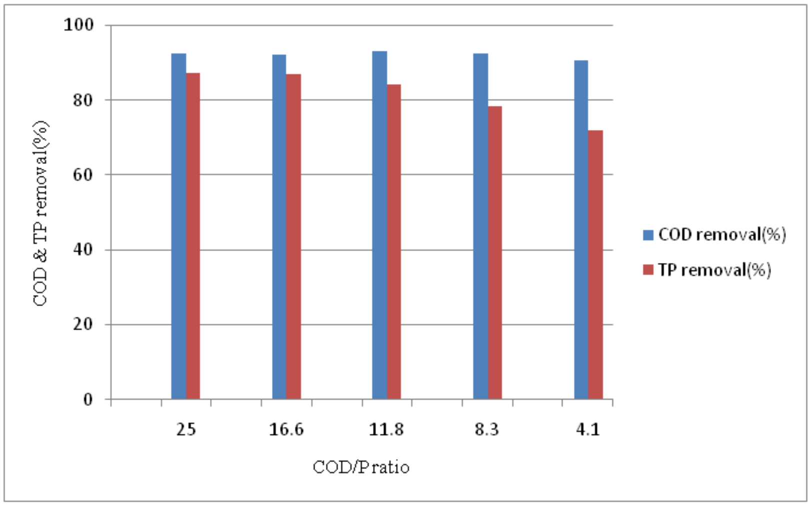

Figure 6. The COD/P ratio variation versus TP and COD removal efficiencies in phase 4.

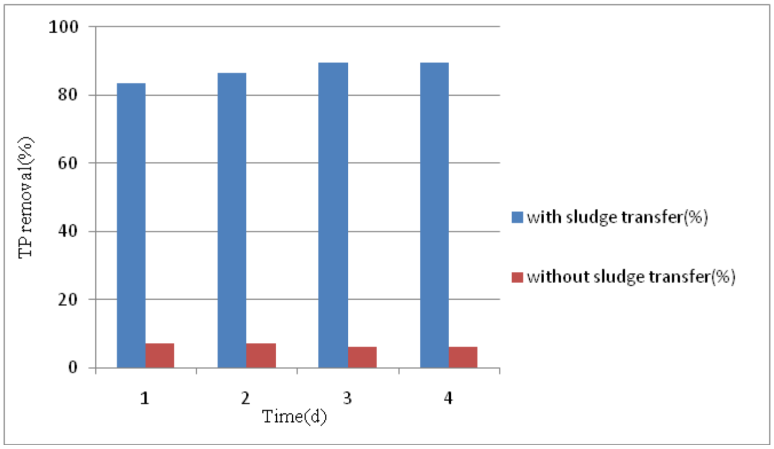

Figure 7. Variation of TP removal efficiency, with the sludge transfer from anaerobic zone to aerobic zone in phase 2 and input phosphate concentration of 16 mg/L

said surely of the phase that had the best COD removal efficiency, because all the phases showed very good removal efficiencies.

As it is seen in figure 4, phase 2 has better efficiency than phase 1 in similar condition of TP input (16 mg/L). The reason can be the 2-time increase in sedimentation time, i.e. anaerobic time and as a result the polyphosphate accumulator bacteria (PAOs) have more time to adsorb organic materials and naturally have more energy to adsorb phosphate in aerating cycle which these lead to increase in phosphate adsorption from wastewater and also increase in phase 2 efficiency than phase 1. These results were comparable with the finding of Zhu in a SBR reactor (Zhu et al., 2006).

As it is depicted in figure 4, the input TP in later days of phase 2 is 8 mg/L, equal to input TP in all days of phase 3, and thus this can be proper for a comparison in equal conditions. Without sludge transfer from anaerobic zone to aerobic zone, phase 3 showed better TP removal efficiency than phase 2. In addition to its better efficiency than phase 2, sludge transfer problems do not exist in phase 3 and this is the other advantage of phase 3. Bassin et al studied nitrogen and phosphate removal in aerobic granular sludge reactors and showed that PAOs are selected in alternative anaerobic/aerobic conditions and this can be another reason for preference of phase 3 because it has several anaerobic/aerobic alternations (Bassin et al., 2012). The input COD and TP in the beginning of phase 4 were 550 mg/L and 8 mg/L respectively which was similar to phase 3, but phase 4 had a better efficiency than phase 3 which it can be due to shorter anoxic/aerobic altercations in phase 4. This finding is in good agreement with Uygar and Kargi 2004 results. In their study on inhibition effect of phenol on removal of nutrients in a 5-step discontinuous reactor, stated that shorter anoxic/aerobic periods leads to better nutrient removal efficiency.

To investigate the COD/P ratio on input COD and TP removal, with stabilizing the TP value in about 60 mg/L, the COD value was reduced from 1500 mg/L to 250 mg/L. In COD/P ratio of about 25 to 4.1 which corresponds to input COD concentration range from 1500 mg/L to 250 mg/L, the COD removal efficiency was not affected considerably and remain about 92% until the end of phase 4, but the TP removal efficiency decreased in this range. Thus the optimum COD/P ratio for COD removal efficiency was all the said range and the optimum COD/P ratio for TP removal was about 25 and 16.5 which its corresponding input COD and TP removal efficiency were 1500 mg/L and 1000 mg/L and 87% and 87% respectively. This means that with decreasing the COD/P ratio, the COD removal efficiency remains constant but the TP removal efficiency decreased and also more than 70% of phosphorous removal occurred in all the COD/TP ratios. In the study of Broughton et al. 2008 on phosphorous removal in different COD/P ratios in a SBR reactor, for input concentration of 50 mg PO_4-P/L, the complete removal efficiency was obtained in COD/P ratio of 15 which is very close to the ratio obtained in our study.

According to figure 7, this positive effect is seen in phase 2, for example in input TP concentration of 16 mg/L in phase 2, the amount of output TP was 14 mg/L without sludge transfer from anaerobic zone to aerobic zone, while after sludge transfer, the amount of output TP reached to 1.6 mg/L. This result is in agreement with Patel et al. 2006 results. They investigated phosphorous removal in a fluidized bed bioreactor with sludge transfer from anoxic zone to aerobic zone and reached phosphorous removal efficiencies of 65% and 85% for presence and absence of sludge transfer conditions respectively. According to the results brought in Figure 7, a considerable increase in TP removal efficiency (to 93.7%) can be seen in phase 2 with sludge transfer to aerobic zone, while without sludge transfer the TP removal efficiency became negative, but there was no need to this. Fu et al. 2009 surveyed the simultaneous nitrification and denitrification coupled with phosphorus removal in a modified anoxic/oxic-membrane bioreactor (A/O-MBR) and figured out that sludge transfer from anaerobic zone to aerobic zone in most of biologic phosphorous removal processes causes increase in PAOs aggregation in aerobic zone and consequently have a positive effect on phosphate removal efficiency.

As it is illustrated in figure 5 for phase 4, when an aerating phase ended and its subsequent sedimentation phase starts, the dissolved oxygen (DO) become 0 mg/L O_2 in the least possible time, i.e. about 15 min. The more DO fall rate is, the more net anaerobic time is, therefore there is more time to adsorb organic materials and this means that there will be rise in COD and TP removal efficiencies and also according to figure 5, the more DO increase slope is in aerating cycle, the more net aerobic time is and the PAOs bacteria have more time to adsorb phosphate and for mixing cycle (anoxic), it is similar to anaerobic cycle (Oehmen et al., 2010). Alternative aerobic and anaerobic cycles in this system lead to better adsorption of organic materials in aerobic steps and use of these materials for phosphate removal in anaerobic steps. The bottom of the reactor which is the anaerobic sector helps better reproduction of phosphate absorber bacteria and as a result the phosphate removal increases.

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