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COMBINED ANAEROBIC-AEROBIC SYSTEM FOR TREATMENT OF TEXTILE WASTEWATER

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Abstract

Textile manufacturing consumes a considerable amount of water in its manufacturing processes. The water is primarily utilized in the dyeing and finishing operations of the textile establishments. Considering both the volume generated and the effluent composition, the textile industry wastewater is rated as the most polluting among all industrial sectors. In this study a combined anaerobic-aerobic reactor was operated continuously for treatment of textile wastewater. Cosmo balls were used to function as growth media for microorganisms in anaerobic reactor. Effect of pH, dissolved oxygen, and organic changes in nitrification and denatrification process were investigated. The results indicated that over 84.62% ammonia nitrogen and about 98.9% volatile suspended solid (VSS) removal efficiency could be obtained. Dissolved oxygen (DO), pH were shown to have only slight influences on the nitrification process; and for each 10% removal of nitrogen, only 3% of pH changes were achieved.

Keywords: Anaerobic, Aerobic, Nitrification, Denitrification, Textile wastewater.

1. Introduction

The textile industry, apart from being an important contributor to the economy of numerous countries, is also a major source of various liquid, solid and gaseous wastes. This kind of industrial activity can have a negative impact on the environment, both in terms of pollutant discharge as well as of water and energy consumption. Although the amount of water used and wastewater generated is largely dependent upon the

Nomenclatures

SSC	Steady State Condition
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
OLR	Organic Loading Rate
VSS	Volatile Suspended Solid
TSS	Total Suspended Solid
HRT	Hydraulic Retention Time
BNR	Biological Nitrogen Removal
PVC	Polyvinyl chloride
NH_4-N	Ammonia nitrogen
NO_3	Nitrate
NO_2	Nitride

specific type of operations followed, in general, dyeing, washing, and finishing operations exert the greatest demand [1]. For instance, a relatively recent survey of the Malaysian textile industry has revealed that the volume of wastewater generated by dyeing and finishing operations ranged from 73 to 167m^3 per ton of product [2].

Anaerobic digestion is widely used to remove organic matter from high strength wastewaters because of its relatively low sludge production and energy needs. Organic nitrogenous compounds present in the wastewater, such as proteins, amino acids or urea, are mainly reduced to ammonia which is not further degraded in anaerobic conditions. The discharge of effluents containing ammonia is undesirable because it causes excessive oxygen demand in the receiving waters. Ammonia toxicity on aquatic life is also possible at high concentrations and high pH values. Complete nitrogen removal is also necessary where the receiving water is a water supply source for downstream users, since eutrophication and nitrate enrichment should be avoided.

In the case of a wastewater with a low COD/TKN ratio, organic carbon content of the digested effluent may be insufficient to achieve complete denitrification and the addition of an external carbon source is then required.

Earlier studies [3] have shown that nitrogen and carbon can be effectively removed from synthetic wastewaters using coupled aerobic and anaerobic filters, where methane production and denitrification will be encouraged to take place in the anaerobic filter while nitrification and final effluent polishing will take place in the aerobic filter. Attempts to carry out denitrification and methane production in a completely mixed reactor have not proved very effective [4] because nitrogen oxides have been found to inhibit (reversibly) methanogenic bacteria [5, 6]. Furthermore, dissimilatory nitrate reduction to ammonia can occur in the system depending on the type of carbon compounds present in the system. Consequently, biofilm reactors have been used in the combined denitrification/anaerobic digestion system because the fixed nature of the media enables the creation of macro and micro-environments within the system, so that the different bacteria involved in the reactions can then grow and concentrate in zones within the reactor favourable to their metabolic activities [4, 7]. The use of biofilm reactors is good for wastewaters containing relatively small amounts of suspended solids. When the wastewater contains significant quantities of solids as in most textile and food processing wastewaters, the use of suspended growth reactors becomes inevitable, and presently very little has been done on nitrate reduction in suspended growth anaerobic systems. Studies with up-flow anaerobic sludge blanket (UASB) reactors have been reported [8], but UASB reactors have a very long start-up time for the granules to develop, thus limiting the scope of their application. This study therefore attempts to investigate the effectiveness of the combined anaerobic-aerobic reactor to treat textile wastewater in term of nitrogen removal.

2. Materials and Methods

2.1 Source of raw textile wastewater

The industrial wastewater used was collected from a textile factory located in the Balakong, Selangor state, in Malaysia. The various waste streams from the dyeing, printing, washing, de-sizing, scouring, mercerizing, and bleaching operations were collected and combined together in a storage tank. Since the combined wastewater was in the alkaline pH range (8.7–10.8), the pH was adjusted to around the neutral mark by adding a concentrated solution (96%, w/w) of sulfuric acid (H_2SO_4), prior to feeding to the bioreactors, in order to minimize any potential toxic and/or inhibitory effects on the biomass [9, 10]. A summary of important influent characteristics is presented (Table 1).

2.2 Set up of experimental design

A laboratory scale combined anaerobic-aerobic reactor was set up to investigate the effectiveness of the system to treat textile wastewater in term of nitrogen removal (Fig. 1).

2.2.1 Anaerobic reactor

The anaerobic reactor, made of transparent PVC, has a diameter of 30 cm, height of 30 cm, and total working volume of 18 litres. The reactor was filled up with supporting particles (Cosmo ball) for immobilization of microorganism in the system, and a total of 2-liter active sludge from palm oil mill was collected from Hulu Langat, Malaysia and fed into the reactor. The total surface area of support material was 192.56m^2.

2.2.2 Aerobic reactor

The aerobic reactor is made of transparent PVC, has a diameter of 20 cm, height of 48 cm, and total working volume of 9 litre. A total of 1 liter sewage sludge from Indah Water Konsortium (IWK) was collected and fed into the aerobic reactor.

Acclimatization of the aerobic sludge was not as critical as compared to anaerobic reactor due to primary function of the aerobic reactor was meant for polishing only. Air was supplied by a fine bubble diffuser; flow was regulated at 6 mg/l/min by a flow meter.

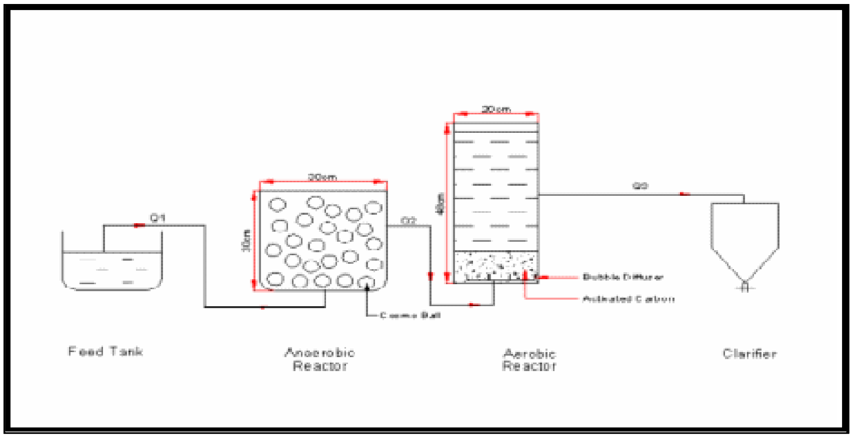

Fig.1. Schematic Drawing of Combined Anaerobic- Aerobic System.

The study was carried out in four different hydraulic retention times, 24, 18, 12, and 8 hours respectively, with the operating conditions showing in Table 2 which were divided into 4 phases. Each of the phases lasted for 14 days in order to allow biomass flocs to develop inside the reactors for biodegradation of the influent organic substrate.

2.3. Feeding criteria

The first load of Textile wastewater with organic loading rate (OLR) 1 kg COD/liter/d was fed into anaerobic reactor on Week 1 and continued till the end of Week 2. The influent COD was kept almost constant (500 ppm) throughout the entire 14 days period. The OLR was subsequently increased to 2 kg COD/liter/d in Week 3 to Week 4. On Week 5 to Week 6, the OLR was increased to 3 kg COD/liter/d and finally raised up to 4 kg COD/liter/d for Week 7 to Week 8 to complete the 4 OLR in this study. The OLR is corresponding to the HRT of 24, 18, 12 and 8 hours respectively. The incremental increase of OLR was made after steady state conditions (SSC) were attained. The growth of new cells is offset by the death of old cells. SSC were considered to occur when the treated COD concentrations were constant for a period of 3-4 days.

2.4 Analytical methods

Liquid effluents were analyzed according to Standard Methods for Examination of Water and Wastewater [11]. The following parameters were determined, pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Volatile Suspended Solid (VSS), Total Suspended Solid (TSS), Ammonia , Nitrate, and Nitrite.

3. Results and Discussion

3.1 Combined system acclimation

For most industrial wastewaters, an acclimation period is necessary in order to gradually expose the microbial community to the potentially inhibitory or toxic organic compounds present. This allows for the development of appropriate enzyme-producing genes that are essential to induce biodegradation [12, 13]. In this study, the feeding pattern followed (described in section 2.3) appeared to be successful. It should be noted that despite the relatively low biodegradability potential of the wastewater used, acclimatized biomass was able to remove a much higher amount of organic matter.

3.2 Nitrogen removal

In phase I where the HRT was around 24 and OLR applied was 1 kg COD/m^3/d, anaerobic reactor achieved removal efficiency of 60%, while the aerobic system achieved 80% NH_4-N removal (Fig. 2). In phase II the HRT was reduced to 18, and the OLR increased to 2 kg COD/m^3/d, anaerobic reactor kept the previous value of removal efficiency (60%), while the aerobic reactor reached 85% in removal efficiency of NH_4-N.The result from phases (III-IV) indicated that any further decrease in the HRT with the increase of OLR, result in the gradual reduction in the removal efficiency of the both reactors (Fig. 2).

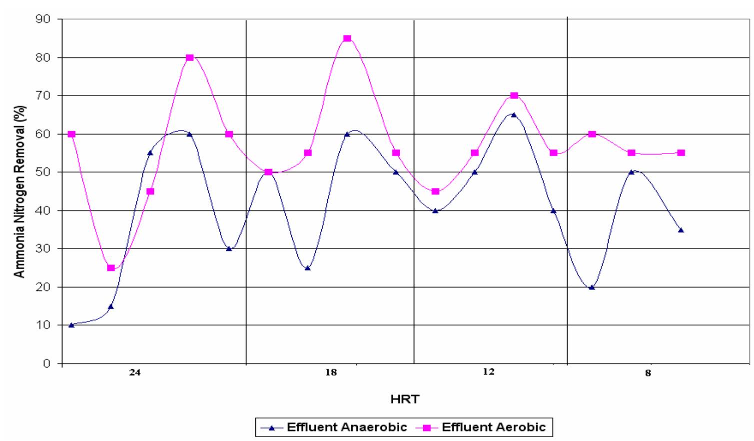

Fig.2. Effect of HRT on the Removal of Ammonia in the Combined System.

It was found that the result of the final treated effluent in the aerobic system was low compared to the anaerobic system effluent. This was due to nitrification process, which had occurred in the aerobic system. The nitrification process was not 100% completed due to the high organic load and the time needed for regeneration of biofilm was too short to allow adequate colonization of nitrifying bacteria to occur [14]. Also the aeration time was too short to allow the completion of 100% nitrification process.

Figure 3 shows the conversion of nitrate for the combined treatment plant. It showed that the nitrate conversion in the aerobic system was twice as high as in the anaerobic one. This is due to the conversion of ammonia to nitrite and from nitrite to nitrate.

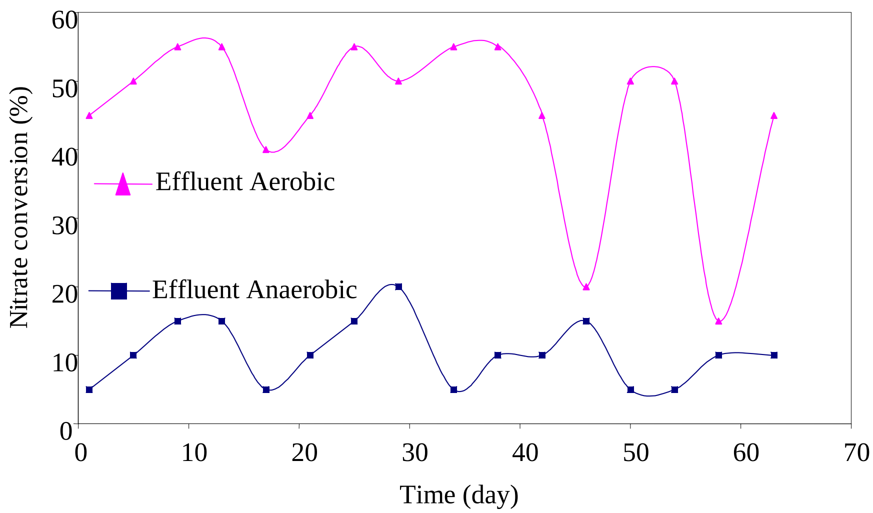

Fig. 3. Nitrate Conversion during the Treatment Process.

3.3 Influence of organic changes on nitrification

Previous studies carried by Osada *et al.*, [15], showed that organic such as BOD and COD of the influent and effluent of anaerobic have great influence on the nitrification process. The result of this study showed that the removal of NH_4 increased with an increase of the organic loading materials and HRT. The COD/NH_4 ratio also has an influence on the removal and efficiencies of the Anaerobic –Aerobic process. The result of this study showed that there was no effect of ammonia removal within the range of 0 to 2.0 of COD/NH_4 ratio (Fig. 4). The optimum COD/NH_4 ratio for removal of ammonia was 7.2.

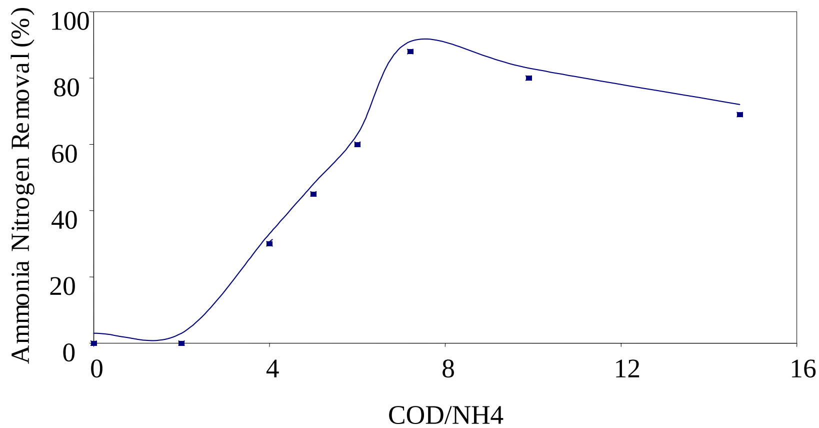

Fig.4. The Relation of COD/NH_4 Ratio and NH_4-N removal (%).

Lee *et al*. [16] reported that the ammonia removal efficiencies decreased with an increase in NH_4 loading of wastewater. The result also showed that at influent COD/NH_4 of 7.2, 9.9, and 14.7, the removal efficiencies in the combined system were 88%, 80%, and 69% respectively. Osada *et al*. [15] Confirmed that the optimum influent COD/NH_4 ratio for nitrogen removal was around 14.0. At high influent COD/NH_4 ratios, nitrogen removal efficiency was limited by incomplete ammonia oxidation, as the high organic load was not removed in the unaerated zone that affects the nitrification process. Although ammonia was completely oxidized for lower COD/NH_4 ratios, there was also a corresponding build-up in the nitrite and nitrate concentration due to insufficient carbon for the denitrification [15].

3.4 Influence of dissolved Oxygen and pH changes on nitrification

The low levels of dissolved oxygen (DO) concentration significantly affect nitrification [17]. However, the results showed that the dissolved oxygen in this study was sufficient for the nitrification process although the results were higher than that reported by the other researcher (Table 3).

Figure 5 showed the influence of dissolved oxygen on nitrification process, which indicated that, for each 5% changes in dissolved oxygen in aerobic reactor, 10% removal of nitrogen was achieved. So, it is clear that dissolved oxygen is one of the factors that affect the removal of nitrogen. Previous studies showed that, the nitrification rate was increased with increasing dissolved oxygen in the range of 1-3 mg/l and decreased with the range of 0.3-0.5-mg/l [20]. In order to achieve a NH_4-N removal of above 60%, the dissolved oxygen concentration in the aerobic system should be maintained above 1 mg/l [21]. The higher the dissolved oxygen concentration, the higher the NH_4-N removal obtained. The dissolved oxygen is essential for nitrification process because it acts as an electron acceptor in the biochemical reaction involved. Therefore dissolved oxygen concentration must be higher than 2 mg/l in order to prevent the possibility of oxygen limitation.

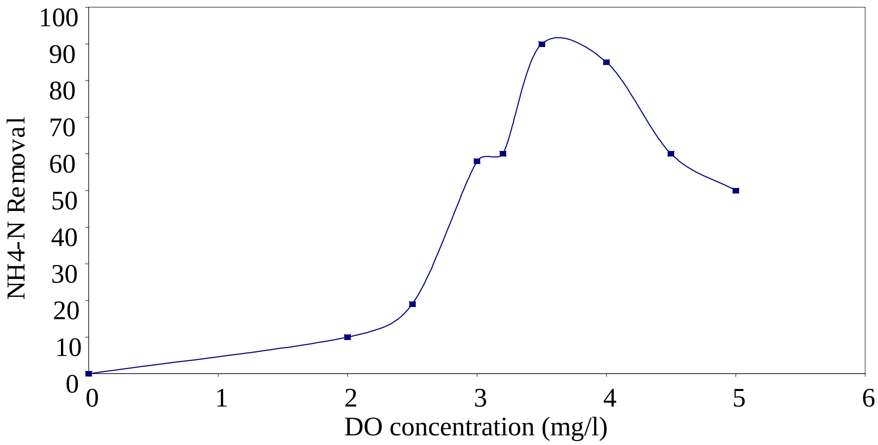

Fig.5. Influence of Dissolved Oxygen on Nitrification.

The pH value showed a slightly difference between the system. The average pH for anaerobic and aerobic system was 7.0 and 6.9 respectively. Figure 6 reflects the influence of pH on nitrification rate, it also showed that only little changes on nitrification rate, caused by pH range of 6.7-7.8.

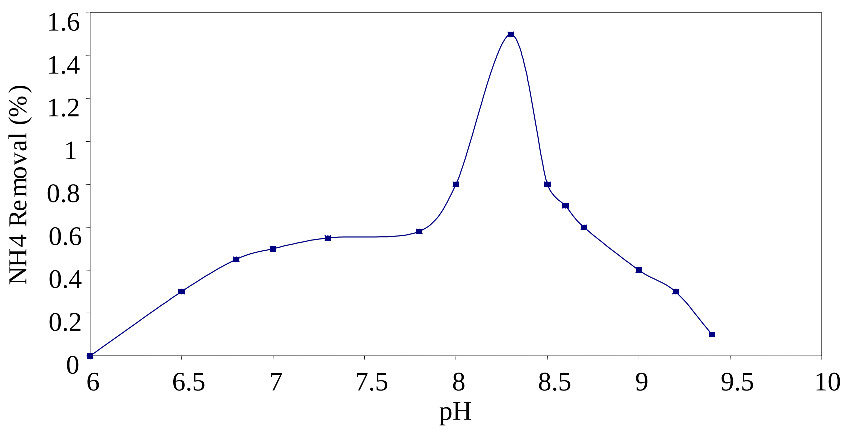

Fig.6. Influence of pH of the Combined System on Nitrification.

The optimum pH of this study was 8.3 and the nitrification rate will fall almost to zero at pH 9.6 and the nitrification decreases as the pH decreases. The optimum pH in previous studies for nitrification was in the range of 7.2-8.6. [22, 23]. Nitrification practically stops at pH below 6.3. In comparison with the results of this study, the pH obtained was still within the range of acceptable pH and will enhance the nitrification process.

3.5 Evaluation of denitrification rate

The denitrification rate was varying during the 63 day of the process. The rate was largely dependent on the concentration of nitrate and volatile suspended solids on that day (Fig. 7). As seen from Fig. 7, the rate varies from 0.4 to 1.2 mg NO_3/ mg VSS.day. The COD/NO_3 ratio was approximately 5.26 and it was low compared to the previous studies. The relationship between COD/NO_3 ratio and denitrification rate can be seen in Fig. 8, and it showed that for each 5% changes of COD/NO_3 ratio, 0.2 denitrification rates was achieved. The minimum COD/NO_3 ratio requirement for effective denitrification in anaerobic filters was reported to be between 7.5 and 9 [23]. Performance of a new biological aerated filter for complete nitrogen removal based on simultaneous nitrification and denitrification was evaluated by [24] using C/N ratio between 6 and 7.5. They also reported that if the ratio was higher than 7.5, the carbon was burned off by oxygen.

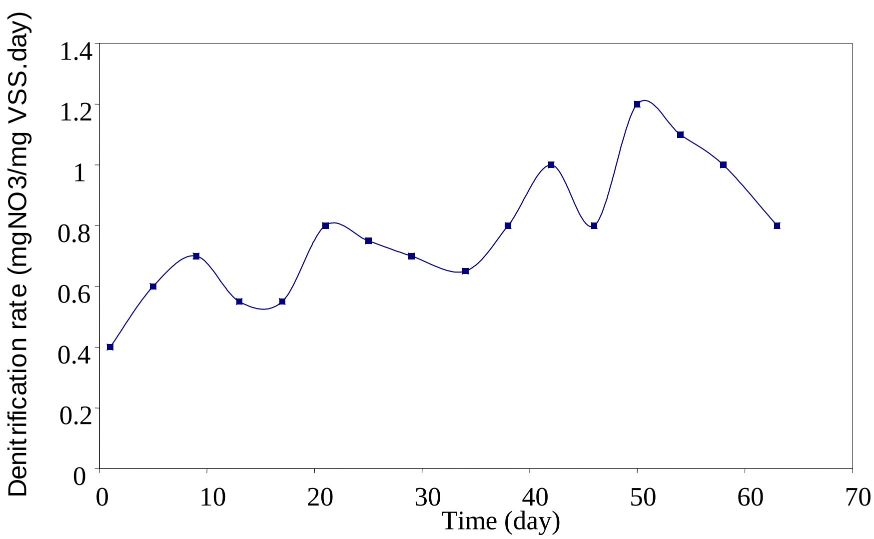

Fig.7. Denitrification Rate over the Time.

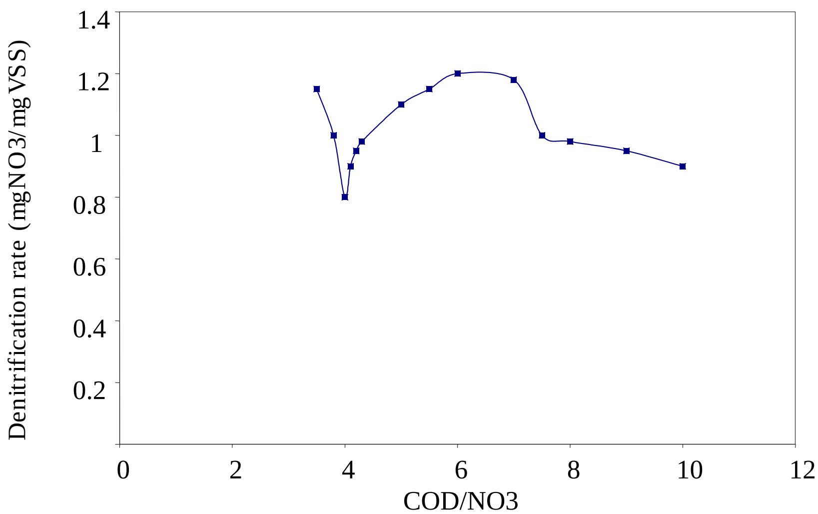

Fig.8. The Relation of COD/NO_3 Ratio and Denitrification Rate.

3.6 Influence of dissolved Oxygen and pH changes on denitrification

Many investigators have reported various results for the influence of oxygen on the biochemistry of the denitrification process. Figure 9 shows the decreasing of denitrification rate with the increasing dissolved oxygen concentration. It appeared that the results from this study were comparable to previous studies (Table 4), with the facts that dissolved oxygen would inhibit denitrification process, if it was present in large amount. In addition, there was an explanation that oxygen either represses the formation of the enzyme nitrate reductase or acts as an electron acceptor, thereby preventing the reduction of nitrate [28].

Figure 10 Shows that the most suitable pH for denitrification process was below 8, and the rate of denitrification was reduced with increasing pH. Previous studies showed that, the effect of pH on nitrification was not significant if the denitrification was carried out between the ranges of pH 6.5-8 [20]. The optimal pH for denitrification varies with the types of organisms present but in general a neutral or slightly alkaline condition was suitable [29]. However, the range of pH value used for denitrification in previous studies was varied in the range of 7.0 to 7.5 [30].

3.7 Organic removal

Figures 11and 12 show the removal efficiency of BOD and COD on the combined anaerobic and aerobic system during the different HRT. It was observed that the removal rate of the both parameters (COD, BOD) in the aerobic system was higher when compared with that in the anaerobic system. In this study the anaerobic system achieves final BOD removal value of 40% in the effluent, while 65% removal for the effluent in the aerobic system (HRT= 8) (Figure 11). In anaerobic system, the COD removal achieved in the effluent was 50% whereas the value of 75% in the aerobic system (HRT= 8) (Fig. 12).

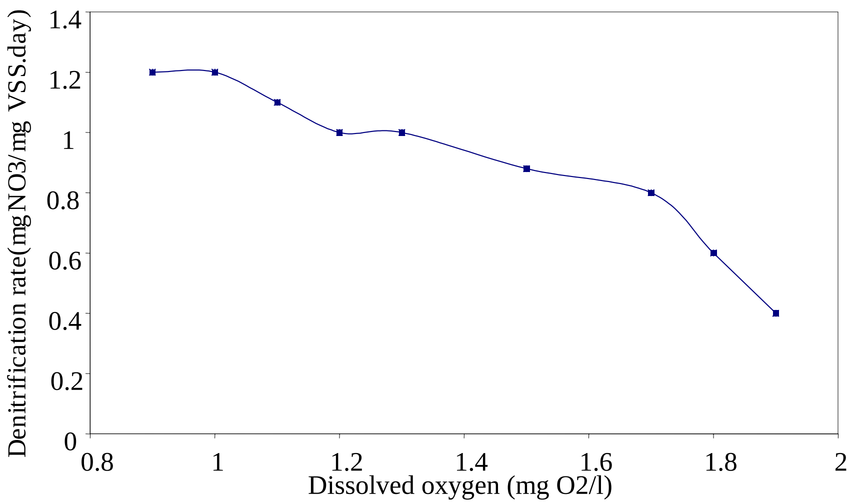

Fig. 9. Influence of Dissolved Oxygen on Denitrification.

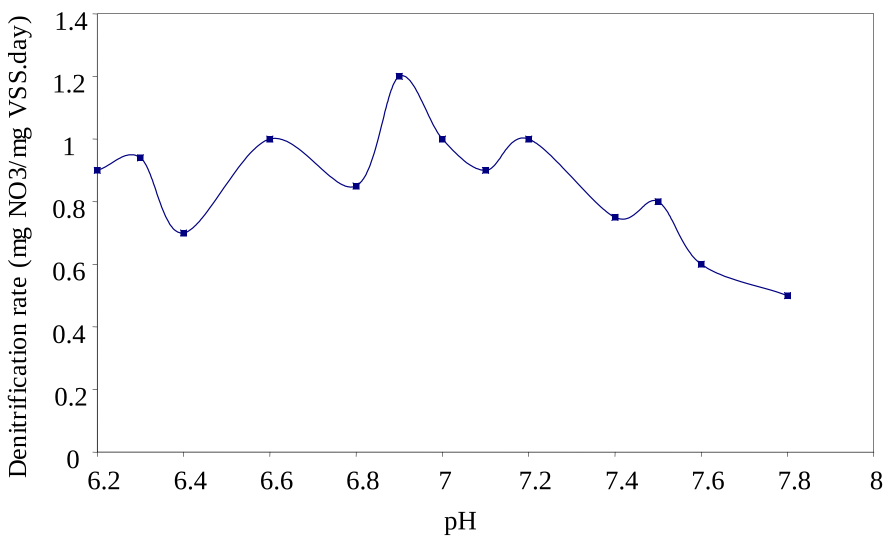

Fig.10. Influence of pH of the Combined System on Denitrification.

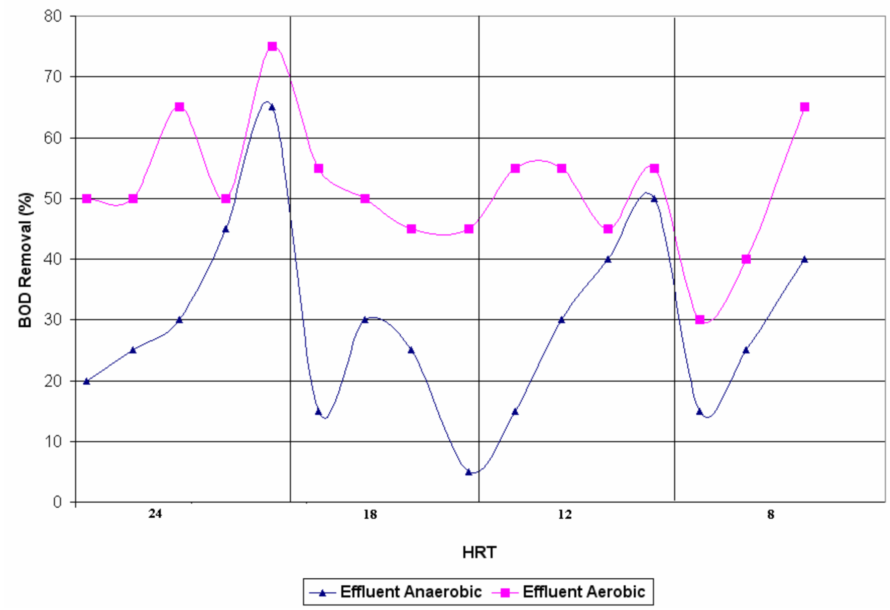

Fig.11. Effect of HRT on BOD Removal of the Combined System.

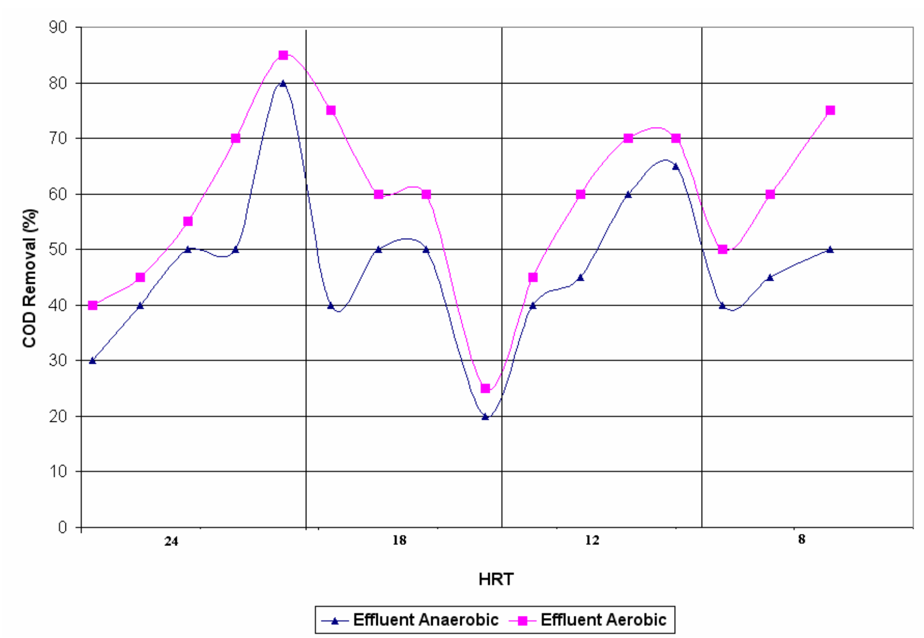

Fig.12. Effect of HRT on COD Removal of the Combined System.

3.8 Effect of organic loading on the effluent quality

The percentage of BOD removal ranges from 38% to 65% with various organic loading rates (OLR) for operational period, while for the performance based on the COD organic loading, the percentage removal was ranging from 35% to 60%. From the result obtained, it was found that the higher organic loading for BOD and COD, the higher the removal rate. It also had shown that the biological nitrogen removal (BNR) system has a low sensitivity on organic loading variations.

The concentration of Total Suspended Solid (TSS) and Volatile Suspended Solid (VSS) in the final effluent was ranging from 10.0- 22.0 mg/l and 0.9- 32.2 mg/l respectively, while the percentage of removal rate for TSS and VSS are about 70.2% and 98.9% respectively.

4. Conclusions

This study concluded that the combined anaerobic-aerobic system was able to treat high strength textile wastewater. The maximum removal of ammonia nitrogen, BOD, COD, VSS were 84.62%, 63.64%, 60% and 98.9% respectively. The concentrations level of ammonia nitrogen, BOD and COD in the final effluent were found to be 1.11 mg/l, 13.17 mg/l and 108.75 mg/l respectively.

Dissolved oxygen, pH were shown to have only slight influences on the nitrification process; and for each 10% removal of nitrogen, only 3% of pH changes were achieved. The changes of COD/NO_3 at 28% gave 0.06 mg NO_3/VSS denitrification rate and this rate will decrease with increasing of dissolved oxygen concentration.

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