Color Removal of Real Textile Wastewater by Sequential Anaerobic and Aerobic Reactors

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Abstract Textile wastewater from the Pusan Dyeing Industrial Complex (PDIC) was treated utilizing a two-stage continuous system, composed of an upflow anaerobic sludge blanket reactor and an activated sludge reactor. The effects of color and organic loading rates were studied by varying the hydraulic retention time and influent glucose concentration. The maximum color load to satisfy the legal discharge limit of color intensity in Korea (400 ADMI, unit of the American Dye Manufacturers Institute) was estimated to be 2,700 ADMI·L^{-1} day^{-1}. This study indicates that the two-stage anaerobic/aerobic reaction system is potentially useful in the treatment of textile wastewater.

Keywords: textile wastewater, color removal, anaerobic/aerobic treatment, UASB

Textile wastewater usually contains refractory dyes and other organic chemicals. It creates a variety of problems in the natural aquatic environment due to its intense color and toxicity [1]. The traditional activated sludge process, a simple biological process, is not effective in the treatment of textile wastewater, since most aerobic bacteria are incapable of degrading the dye molecules [2]. Some anaerobic bacteria, however, have been reported to decolorize them by enzymatic reduction of chromogenic groups [3,4]. Once the chromogens are removed, further degradation by aerobic bacteria can occur [5].

Many reactor studies have been performed on the treatment of textile wastewater, normally using artificial wastewater containing azo dyes. Several monoazo dyes, such as Mordant Yellow 3 [5], Acid Red 18, Acid Red 14, and Acid Orange 10 [4] have been successfully treated by a two-step, anaerobic/aerobic process. For diazo dyes, especially Remazol Black B (also known as Reactive Black 5), the results were somewhat controversial; Sponza and Isik [6] and Oxspring *et al.* [7] reported a decolorization efficiency of over 95% in the upflow anaerobic sludge blanket (UASB) reactor or in an upflow anaerobic filter, while Panswad *et al.* [8] and Ganesh *et al.* [9] reported an efficiency of only around 50% in an anaerobic/aerobic sequential batch reactor, or in an anaerobic digester. Studies using actual wastewater have been extremely limited. Li *et al.* [10] reported that a sequential anaerobic/aerobic fluidized bed system could reduce COD (chemical oxygen demand) of textile wastewater to a certain extent, but color removal was not investigated. Recently, Sen and Demirer [11] reported that color in real textile wastewater could be reduced by 54~59% (measured by absorbance at 669 nm) in an anaerobic fluidized bed reactor, operated at an HRT (hydraulic retention time) of 24 h, and an organic loading rate of 3 g COD L^{-1} day^{-1}.

In the present study, we report the results of treatment of wastewater from the Pusan Dyeing Industrial Complex (PDIC) (Pusan, Korea) by a two-step continuous process consisting of a UASB reactor and an activated sludge reactor. We focused on the removal of both color and COD at various organic loading rates, and attempted to evaluate the potential of the two-step system in treating the PDIC wastewater.

The PDIC receives wastewater from approximately 50 textile-dyeing companies in the complex. Information regarding the types and amounts of dyes and other relevant chemicals used by each company are proprietary, and were thus unavailable. However, based on the textile products from this complex, it was speculated that reactive dyes comprised the majority of coloring agents being used in the companies within the complex, and were expected to appear in the wastewater. The wastewater was taken from the collection pond of the PDIC, and stored at 4°C during the experiment. There were daily variations but the typical characteristics of the wastewater were: COD_{Cr}, 440~928 mg/L; BOD_5 (biochemical oxygen demand), 289~489 mg/L; color, 500~1400 ADMI (American Dye Manufacturers Institute); TSS (total suspended solids), 24~67 mg/L; pH, 7.2~11.5; temperature, 33~41°C; and *n*-hexane, 45~91 mg/L. The raw wastewater was supplemented with glucose, $NaHCO_3$, NH_4Cl, K_2HPO_4,

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and KH_2PO_4. The pH was adjusted to 7.0 before use.

Methanogenic granular sludge was obtained from a pilot scale UASB reactor, which had been employed for treating paper-mill wastewater and used as an inoculum for the present UASB reactor. The sludge was elutriated to remove fine particles, and stored at 4°C before use. It had a volatile suspended solids (VSS) concentration of 24.3 g/L and a VSS/TSS ratio of 0.62. Activated sludge for the aerobic reactor was obtained from a domestic wastewater treatment plant in Pusan, Korea. The VSS concentration and VSS/TSS ratio were 3.5 g/L and 0.67, respectively.

The UASB reactor for anaerobic treatment was a 5-L flexi-glass jar with a solid/liquid/gas separator located in the upper section. The activated sludge reactor was also made of flexi-glass, and was separated into two compartments, for aeration (6 L) and settling (2 L). The UASB reactor was kept at 35°C, and the aerobic reactor was kept at room temperature (22~27°C). Initially, the UASB reactor was operated at an HRT of 12~24 h with artificial wastewater, in order to stabilize the methanogenic activity of the granular sludge. The artificial wastewater was prepared as described by Oh *et al.* [12] and contained glucose at a concentration of 2,100 mg/L. After 85 days, the UASB reactor reached a steady state with respect to the soluble COD (sCOD) removal efficiency, 95% and CH_4 production rate, 8 L/day, and real textile wastewater began to be used. The ratio of real wastewater was gradually increased, from 10 to 100% (v/v) between 85 and 138 days, while maintaining the inlet glucose concentration at 2,100 mg/L, and the HRT at 12 h. The aerobic reactor was also operated with artificial wastewater for an initial 46 days before accepting the UASB effluent. The aerobic artificial wastewater was prepared as described by Kim *et al.* [13] and contained glucose at a concentration of 1,000 mg/L. After 46 days, the effluent from the 1st stage anaerobic reactor was added to the feed of the aerobic reactor, with a gradual increase in ratio, from 50 to 100% (v/v) for the next 50 days. During this period, inlet COD concentration of the feed to the 2nd stage aerobic reactor was maintained at a concentration of 1,000 mg/L by adding glucose and the HRT at 11 h. After both reactors were fully stabilized with the real wastewater, the effects of HRT and inlet glucose concentration on the removal of color and COD were studied. Whenever a condition was changed, the reactor was operated at the new condition for the period of 10 times HRT, in order to assure a steady state. When the glucose concentration in the feed was changed, the concentrations of NH_4Cl, K_2HPO_4 and KH_2PO_4 were also changed at the same ratio.

The CH_4 content in the biogas, CH_4 production rate, and sCOD were analyzed as described by Ahn *et al.* [14] and Nakamura and Mtui [15]. Color intensity (ADMI), VSS, TSS, and alkalinity were determined according to the Standard Methods [16].

Fig. 1 shows the effects of the HRT of the UASB reactor (1st stage) on the removal of color and COD. In the 1st stage, HRT was varied at 6, 12, and 18 h while in the 2nd stage, HRT was kept constant at 11 h. The inlet glucose concentration remained constant at a concentration of 2,100 mg/L. During the experiment, the color intensity of the PDIC wastewater varied significantly, as 660 ± 80 ADMI at 6 h HRT, 1,030 ± 240 ADMI at 12 h HRT and 1,010 ± 170 ADMI at 18 h HRT. Fig. 1 indicates that UASB is an efficient system for color removal and that the removal efficiency increases as HRT increases. However, there was significant variation in removal efficiency at the same HRT, which is indicated by relatively high standard deviations. This is attributed to different color intensity, and also other qualities of the wastewater, which cannot be quantified by COD or color intensity. The aerobic reactor contributed nothing to the removal of color. Fig. 1 also shows that the COD removal rate in the 1st stage decreases with decreasing HRT values. However, the overall COD removal efficiency of the two-stage system was almost constant at 92%, regardless of the 1st stage HRT. This indicates that, although not contributing

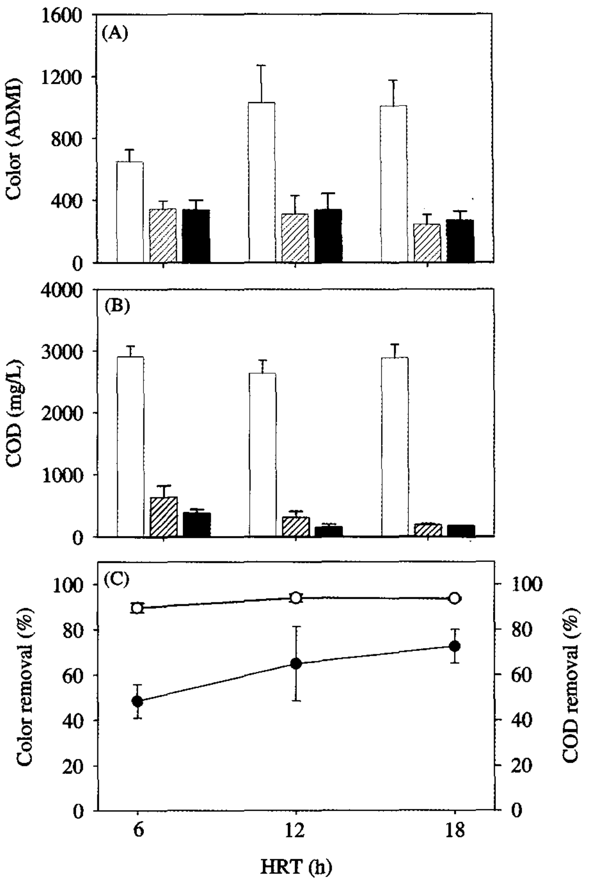

Fig. 1. Effects of the 1st stage HRT on color and COD removal Inlet glucose concentration was 2,100 mg/L and 2nd stage HRT was 11 h. (A) influent color (□), effluent color after aerobic treatment (▨), and effluent color after anaerobic and aerobic treatment (■); (B) inlet COD (□), effluent COD after anaerobic treatment (▨), and effluent COD after anaerobic and aerobic treatment (■); and (C) removal efficiencies of color (●) and COD (○) after anaerobic and aerobic treatment.

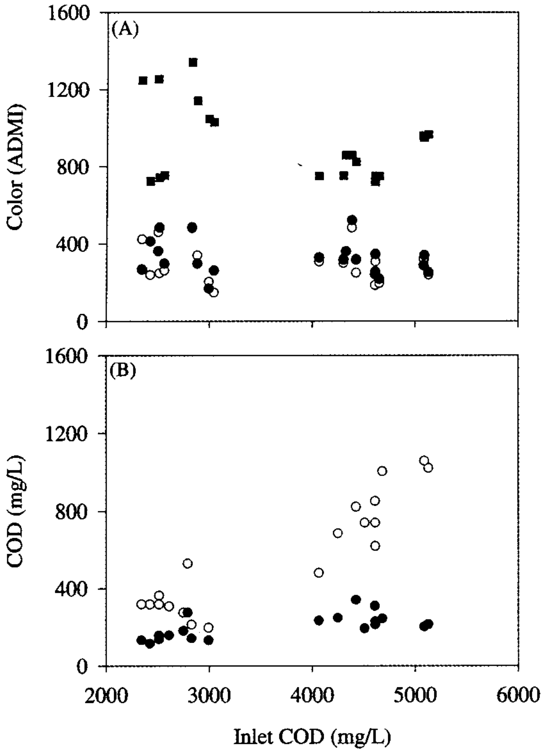

Fig. 2. Effects of 1st stage inlet COD on color and COD removal. HRTs for the 1st and 2nd stages were kept at 12 and 11 h, respectively. Symbols: influent (■), effluent after anaerobic treatment (○), and effluent after anaerobic and aerobic treatment (●).

to color removal, the aerobic reactor played an important role in COD removal. Under the selected operational conditions, the wastewater used for Fig. 1 could be treated to produce an effluent color intensity below 400 ADMI, the current discharge upper limit in Korea.

Fig. 2 shows the effects of the inlet COD on color and COD removal. The glucose concentration was varied in the range of 2,250~4,500 mg COD/L, and the total COD (glucose COD plus wastewater-derived COD) was in a range of 2,340~5,130 mg COD/L. The HRTs for the 1st and 2nd stages were kept constant at 12 and 11 h, respectively. The color intensity of the effluent was less than 400 ADMI in most cases, in spite of some signifycant variations in the influent and effluent. Glucose concentration did not affect color removal efficiency. Glucose or similar carbohydrates are often found in textile wastewater, along with coloring agents, and should be properly treated before the wastewater is discharged. Fig. 2 shows that, with increasing inlet COD, the effluent COD from the UASB reactor increased in an almost linear fashion, and reached 1,000 mg COD/L for the inlet COD of 5,000 mg/L (equivalent to 4,500 mg glucose COD/L). The inlet glucose concentration of 4,500 mg COD/L corresponds to approximately 9.0 g COD L^{-1} day^{-1} as an organic loading rate. In the case of artificial wastewater, which contains glucose as a sole carbon source, a UASB reactor can remove COD at a high rate, typically up to a loading rate of 18 g COD L^{-1} day^{-1}, by more than 95% [17]. Comparing this value with the present one, it becomes clear that the present UASB has a low COD removal efficiency. This must be attributed to the presence of non-biodegradable COD in the PDIC wastewater. However, the possibility that the textile wastewater possesses toxicity on the biological activity of UASB granules cannot be ruled out [18], considering that the aerobic reactor can reduce the COD to a level of less than 300 mg/L.

Although COD is a major contaminant to be treated in wastewater, it is an important nutrient required to maintain the biological activity of microorganisms. This is especially true when dye is degraded in an anaerobic reactor, such as a UASB reactor. For reductive degradation of dye and the maintenance of the methanogenic activity of anaerobic sludge, proper reducing powers should be provided by carbon metabolism [17]. In addition, it is essential to generate biogases, which keep the UASB reactor operating stably by mixing the granular sludge. As a consequence, when the readily usable carbon sources are very low or deficient, the wastewater should be supplemented with proper carbon sources. The BOD_5 of the PDIC wastewater is 289~489 mg/L, which is low for UASB treatment. In a preliminary experiment in a serum bottle with the UASB granules, about 1.0 g glucose/L was required for the efficient color removal of the PDIC wastewater (data not shown). Sen and Demirer [11] have also reported that, by increasing the glucose concentration from 0.5 to 2 g/L in real textile wastewater, the color and COD removal efficiencies of an anaerobic fluidized bed reactor were significantly augmented from 40~44% and 62~66% to 54~59% and 78~82%. In the present study, glucose concentration in the UASB influent was not lowered below 2,100 mg/L for stable operation of the reactor. However, it is clear that the operation cost of the present system for treating textile wastewater is largely dependent on the availability of cheap carbon sources. Further studies to search for a proper carbon source, and to determine operating conditions, including the minimum concentration of the carbon source, should be followed.

In Fig. 3, the results of Figs. 1 and 2 were rearranged in order to illustrate the effects of influent color and COD in terms of loading rates. When the color discharge limit is 400 ADMI and the PDIC wastewater has a color intensity of 500~1,400 ADMI, the present UASB reactor could treat a color load of up to 2,700 ADMI·L L^{-1} day^{-1}) Organic load could be treated at levels of up to 6 g COD L^{-1} day^{-1} with the UASB reactor only, and up to 10 g COD L^{-1} day^{-1} with the subsequent aerobic reactor. These results suggest that the present two-stage system is potentially useful in the treatment of real textile wastewater. The economic feasibility of this approach, and its prospects for long-term operational stability, require further investigation.

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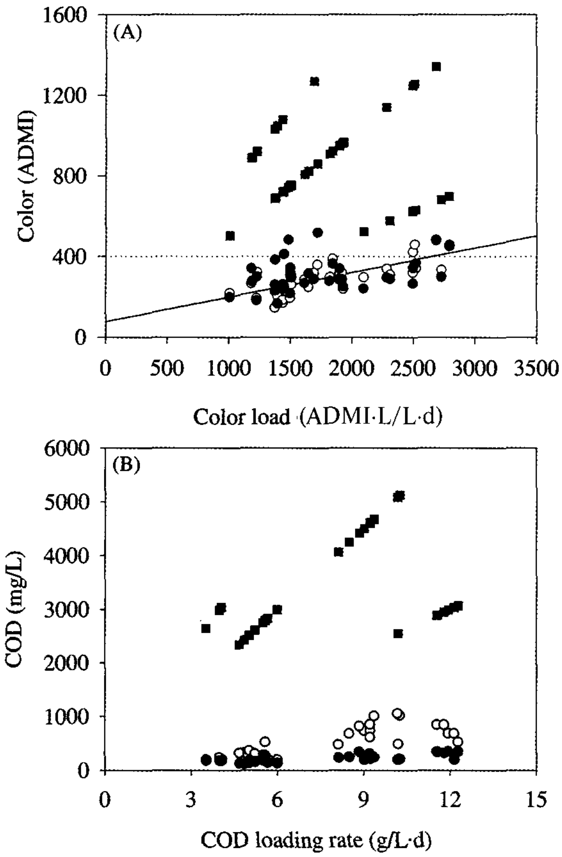

Fig. 3. Loading rate *vs.* effluent concentrations: (A) color and (B) COD. Symbols are the same as in Fig. 2. Solid line represents the regression of effluent color after anaerobic treatment *vs.* color load.

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