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PROSPECTS OF HYBRID UP-FLOW ANAEROBIC SLUDGE BLANKET REACTOR IN TREATING TEXTILE WASTEWATER IN BANGLADESH

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ABSTRACT

In this study, the performance of a lab-scale hybrid up-flow anaerobic sludge blanket (HUASB) reactor treating textile wastewater was evaluated. Biocell filter media was incorporated in the UASB reactor for the attached growth of microorganisms. The wastewater was collected from Mahmud Denims Ltd which had high COD, BOD and color concentration. The reactor was operated under three different conditions: i) textile wastewater mixed up with glucose as food, ii) textile wastewater seeded with sewage sludge and glucose and iii) textile wastewater only. In all cases, two days of incubation period was provided for bacterial growth. In the first case, Klebsiella was the primary bacterium growing in the reactor and the removal efficiency of COD and color was 25% and 56.4% respectively. In the second case, Klebsiella and Escherichia coli were the major bacteria and removal efficiency of COD and color was found to be 38% and 65% respectively. In the last case, Pseudomonas bacterium was dominant in the reactor and removal efficiency of COD, BOD and color was 84%, 93%, and 96~97% respectively. Wastewater treatment without glucose favored the growth of Pseudomonas which has been found to be effective in degrading organics present in textile wastewater. For all cases, the reactor's performance decreased after the third or fourth cycle of treatment. However, the removal of sludge after the third cycle maintained a high degradation efficiency of organics. The performance of the lab-scale HUASB reactor was compared with that of some conventional UASB reactors currently being operated in Bangladesh. Our lab-scale reactor showed better performance than the UASB units of these effluent treatment plants in removing COD, BOD, and color in spite of having significantly lower retention time. So, with proper bacterial growth and maintenance, the HUASB reactor can be a considerable upgrade from conventional UASB and a suitable alternative to conventional processes for the treatment of textile wastewater.

Keywords: *Hybrid UASB, Textile wastewater treatment, Anaerobic process, COD removal, Color removal.*

1. INTRODUCTION

The textile industry contributes a significant portion of the total exports of Bangladesh. Share of Ready-made-garments (RMG) in national export is 85.43% (Bangladesh Bureau of Statistics [BBS],2017). However, the textile industry consumes large quantities of water and produces large volumes of wastewater. It is estimated that textile industries in Bangladesh generated around 217 million m3 of wastewater in 2016 and if the textile industries continue using conventional dyeing practices then wastewater production for the year 2021 will be 349 million m3 (Hossain, Sarker, & Khan, 2018). Wastewater from printing and dyeing units is often rich in color, contains residues of reactive dyes and these dyes are mostly aromatic and heterocyclic organic compounds (Wang, Xue, Huang & Liu, 2011). These structures are complicated and stable which poses a greater difficulty for degradation using conventional wastewater treatment processes (Joshi, Bansal, & Purwar, 2004).

In the past several decades, many techniques have emerged to find an economical and efficient way to treat the textile dyeing wastewater, including physicochemical, biochemical, biological and combined treatment processes. Industries adopting chemical treatment processes are facing the problem of excessive sludge generation which is unmanageable in most developing countries (Samer, 2015). Also, chemically treated water with low regulation may pose an additional health hazard (e.g. formation of trihalomethanes) (Akpor, 2011). Aerobic treatment processes show lower efficiency under increased organic loading, have a high operational cost associated with blower operation and generates a large amount of sludge. These problems have led industry owners to adopt anaerobic wastewater treatment processes which could potentially overcome some of these problems. The Up-flow Anaerobic Sludge Blanket (UASB) Reactor has been successfully implemented to treat wastewater in our neighboring country, India for more than 20 years and its performance was found to be satisfactory (Khalil, Mittal, Raghav, & Rajeev, 2006). Presently over 200 full-scale UASB plants are in operation all over the world for the treatment of both domestic and industrial wastewaters.

UASB reactor is a methanogenic (methane-producing) digester. It works even when the wastewater contains chemical oxygen demand (COD) and biochemical oxygen demand (BOD) value so high that the aerobic treatment becomes ineffective. The UASB reactor reduces COD and BOD concentration to such a level that it can be treated further using aerobic processes. The main advantage of this technology is low capital cost, low energy requirements, low operational and maintenance cost(Miah, 2013). No chemical is needed except for controlling pH. Moreover, the biogas produced bythe UASB reactor can be used to recover energy(Daud et al., 2018). But in this technology, a start-up period of 3-4 months is needed for granule formation in a delicately controlled environment (Hulshoff Pol, De Castro Lopes, Lettinga & Lens, 2004). Besides, COD removal efficiency is about 50%, necessitating further treatments (Amaral, Kato, Florêncio & Gavazza, 2014). If the environment for bacterial growth is disturbed, the reactor fails and an additional maturation period for granules is needed for restarting the reactor. In order to eliminate all these shortcomings, a modification has been proposed to the conventional UASB which is through the introduction of a media for attached growth and the modified setup is termed as hybrid UASB (HUASB). This adjustment has been found to reduce the start-up time, enhance COD and color removal efficiency and to lower down retention time (Priya, Meenambal, Balasubramanian & Perumal, 2015). As this technology works better in a hot climate, it is deemed to be highly suitable for countries like India and Bangladesh. This technology is yet to be implemented in large industrial effluent treatment plants in Bangladesh.

The objective of this study is to evaluate the performance of the HUASB reactor treating textile wastewater in Bangladesh. A lab-scale reactor was operated and bacterial growth, sludge production, COD, BOD, and color removal efficiencies were monitored under different operating conditions.

2. METHODOLOGY

2.1 Wastewater Collection

Textile wastewater from Mahmud Denims Limited, Shafipur, Kaliakoir, Gazipur was used in our experiments. The factory comprises of spinning, weaving, dyeing, and jeans section. The production capacity of thisfactoryis about 1,50,000 Yards/day while consuming about 2500 m^3 water/day. Water used in different processes is mainly groundwater. The wastewater was fed with cow dung at a ratio of 1:3 v/v in the feeding tank. Wastewater was collected in 25L plastic containers from the equalization tank of the industry's ETP. The raw wastewater characteristics are shown in Table 1.

Table 1: Characteristics of raw wastewater

Parameter	**Value**
pH	7.4
Electrical Conductivity (mS/cm)	6.59
Color (Pt-Co Unit)	8700~8900
Dissolved Oxygen (mg/L)	0.06
Phosphate (mg/L)	72
Total Dissolved Solids (mg/L)	1578
Total Suspended Solids (mg/L)	8513
COD (mg/L)	2310~2416

2.2 Experimental Setup

A lab-scale reactor with a capacity of 12.3 liters was fabricated using a transparent acrylic fiber cylinder with a diameter of 3.5 inches and a height of 6.5 feet with a wall thickness of 0.5 inches. The reactor is divided into three zones- Digestion zone, Transition zone, and Settling zone. A Schematic diagram is shown in figure 1.

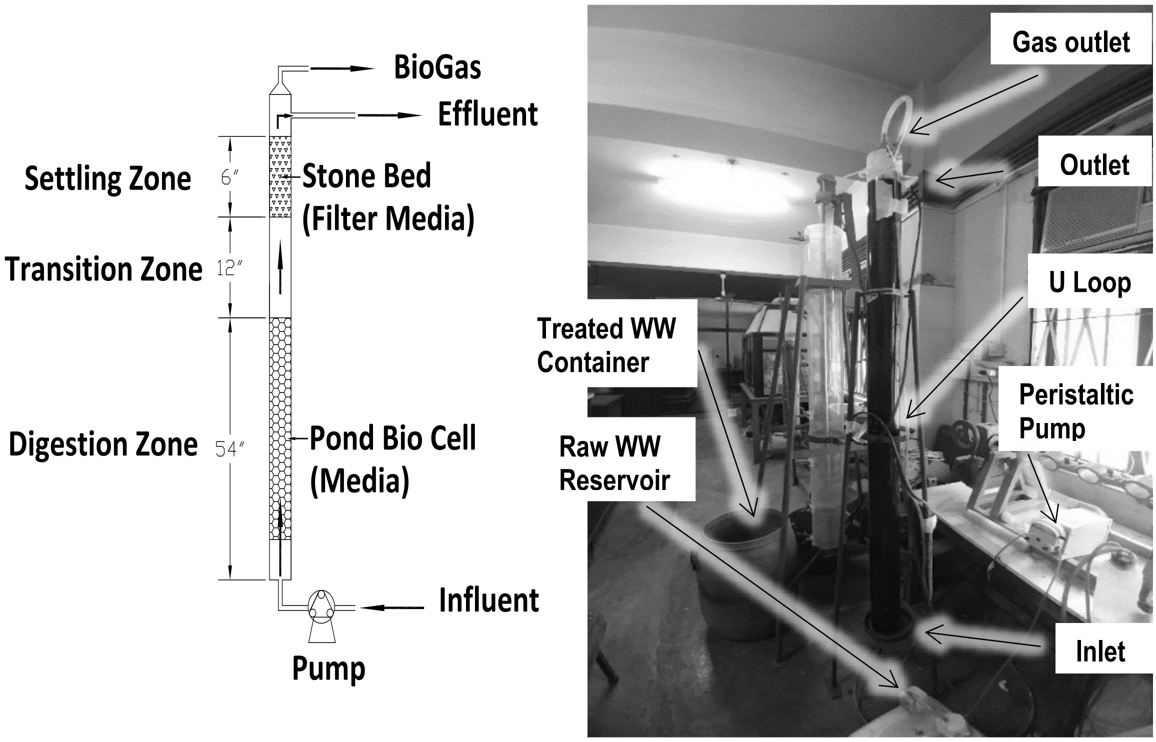


Figure 1: Schematic diagram (left) and image (right) of the experimental setup

The digestion zone was at the lower part of the reactor, 4.5 feet long and filled with pond bio cells (packing media, polypropylene rings of 20 mm diameter) in between 2 fixed screens (0.2-inch diameter screen size). The screens are placed at a distanceof 48 inches to contain the pond bio cells. These bio cells facilitate the growth of microorganisms. 6 inches of space was provided at the bottom of the rector for sludge accumulation. Above the digestion zone, there was a 1-foot blank space as a transition zone. The next 6-inch height was the settling zone filled with fine gravel (passing 3/8 inches sieve and retaining on #4 sieve) held between two similar screens functioning as a filter media. Gravel bed and the packing media reduce the working volume of the reactor to 8.8L. Outlet pipe was connected to the effluent tank through rubber tubing with a U loop. The U loop provided a water seal and prevented the intrusion of atmospheric air into the reactor in order to retain anaerobic conditions in the reactor. A peristaltic pump was used to pump wastewater into the reactor.

2.3 Operational Method

Raw textile wastewater was treated with varying hydraulic retention times (HRT) under different start-up conditions. Five trials were given to treat wastewater using the laboratory setup. Anaerobic seed culture collected from the feeding tank of the ETP plant of Mahmud Denims Limited was used for the inoculation in the HUASB reactor. For the first trial, glucose was mixed with textile wastewater as a source of food for microorganisms. For the second and third trials, glucose and sewage sludge were added during start-up. For the fourth and fifth trials, only textile wastewater was fed in the reactor. An HRT of 2 days was maintained during the reactor set-up period. Wastewater was cycled once a day with intended retention time. 5-6 cycles of wastewater treatment were completed in each trial. Since the reactor's hydraulic characteristics were closer to the plug flow, samples at the inlet were compared with samples taken from the outlet one HRT later. Different parameters such as BOD, COD, color, Electrical Conductivity (EC), pH, Dissolved Oxygen (DO), Oxidation-reduction Potential (ORP), etc. were tested for each condition using standard procedures. DO concentration less than 0.1 mg/L and ORP value less than -300 mV ensured anaerobic condition in the reactor. Bacterial growth was identified whenever there was a significant change in results. The reactor was operated at mesophilic temperature (27±5° C). During winter the temperature was controlled by incorporating a room heater beside the reactor. The pH of the incoming wastewater into the reactor was maintained at 8 for optimal bacterial growth. Effluent pH varied between 5.6~7.5 which indicated that decomposition was taking place in the rector. For the first three trials, the reactor was operated for 5 to 6 cycles without desludging. For the fourth trial, sludge was fully removed after the fourth cycle. Whereas for the fifth trial, sludge was partially removed after the third cycle. For the detection of bacteria, water and sludge samples were taken from the reactor and sent to the pathology lab of Impulse Hospital, Dhaka, Bangladesh.

3. RESULTS AND DISCUSSION

3.1 Bacterial Species

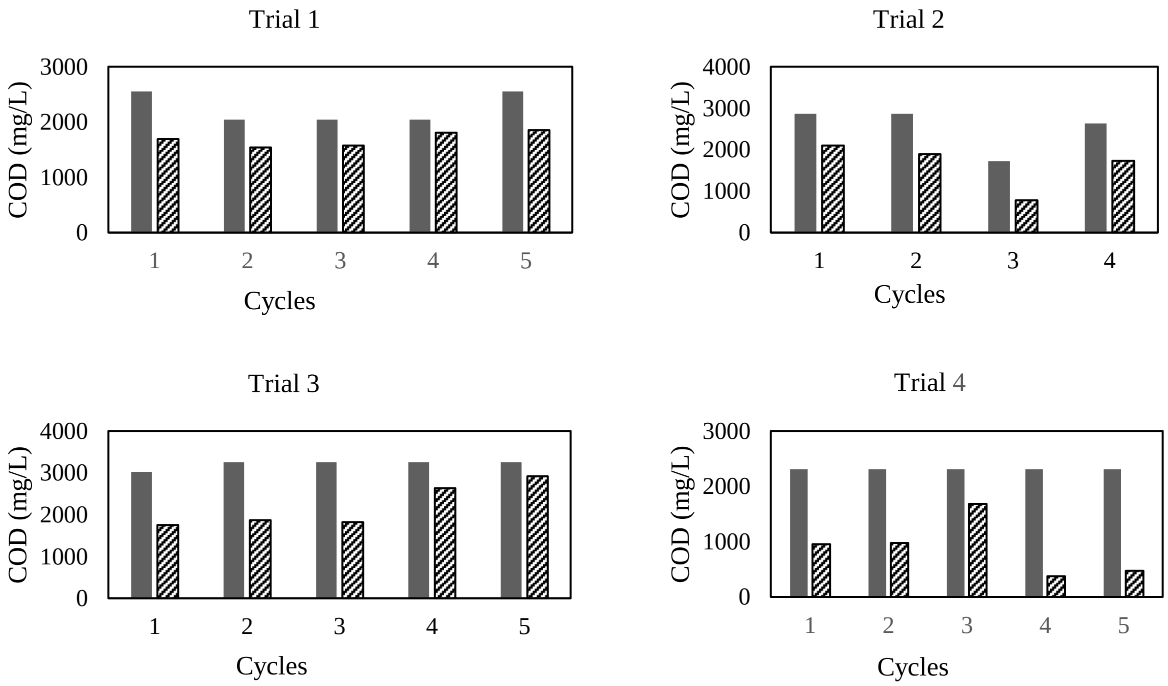
Three types of bacteria were found in the reactor. In the first trial when glucose was added with wastewater, *Klebsiella* was the dominant bacteria. But the addition of sewage sludge in trials 2 and 3 introduced *Escherichia coli* along with *Klebsiella*. Exclusion of both glucose and sewage water in trials 4 and 5 initiated the growth of *Pseudomonas*. All these bacteria are gram-negative, facultative and anaerobic. As the parameters of the environment were kept constant inside the reactor except for food, the dominance of a particular species in the reactor was dependent on the type of food added to the system. The addition of glucose favored the growth of *Klebsiella* and since *E. coli* was present in sewage wastewater, the trials having both glucose and sewage added have both *Klebsiella* and *E. coli*. But when no glucose or sewage sludge was added, *Pseudomonas* was the dominant species in the reactor.*Pseudomonas* has been shown previously to grow in similar environments due to its greater capability in digesting complex hydrocarbons i.e. polycyclic aromatic hydrocarbon (PAH) (Karimi, Habibi & Esvand, 2015).Influent characteristics and corresponding dominant microbes are shown in table 2.

Table 2: Description of the trials and the Dominant Microbes in each trial

Influent	*Klebsiella*	*E. coli*	*Pseudomonas*
Textile wastewater + Glucose, HRT 6 hours (Trial 1)	✓		
Textile Wastewater + Sewage Sludge + Glucose, HRT 8 hours (Trial 2)	✓	✓	
Textile Wastewater + Sewage Sludge + Glucose, HRT 24 hours (Trial 3)	✓	✓	
Textile Wastewater, no additional food, HRT 7 hours (Trial 4)			✓
Textile Wastewater, no additional food, HRT 4 hours (Trial 5)			✓

3.2 COD and Color Removal

In these experiments, the influent wastewater had high COD value (2046 mg/L ~ 3252 mg/L). Influent and effluent COD and COD removal efficiency for different trials are shown in figure 2 and figure 3 respectively. For the first trial, COD removal efficiency gradually decreased from 33.8% to 11.6% from cycle 1 to 4 with the efficiency slightly increasing in the fifth cycle. The average COD removal efficiency is 25%. An HRT of 6 hours was maintained for all cycles and *Klebsiella* was identified in the reactor in this trial. In the second trial, HRT was 8 hours and bacteria in the reactor were mainly *Klebsiella* and *E. coli*. COD removal efficiency gradually increases from 26.7% to 54.5% from cycle 1 to 3 and decreased to 34.3% in the fourth cycle. The average COD removal efficiency was 38% which was slightly higher than the first trial. Increasing HRT from 8 hours to 24 hours in the third trial did not improve the removal efficiency of the reactor. COD removal efficiency remained close to 43% for the first three cycles. However, it drastically decreases to 19% and 10.3% in the fourth and fifth cycles.



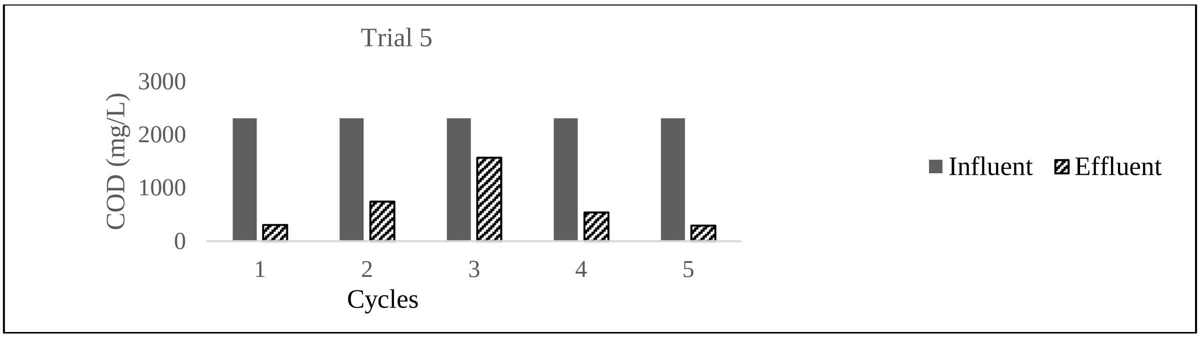


Figure 2: Performance of the reactor in removing COD over different cycles of run for different trials where each trial represents different operating conditions

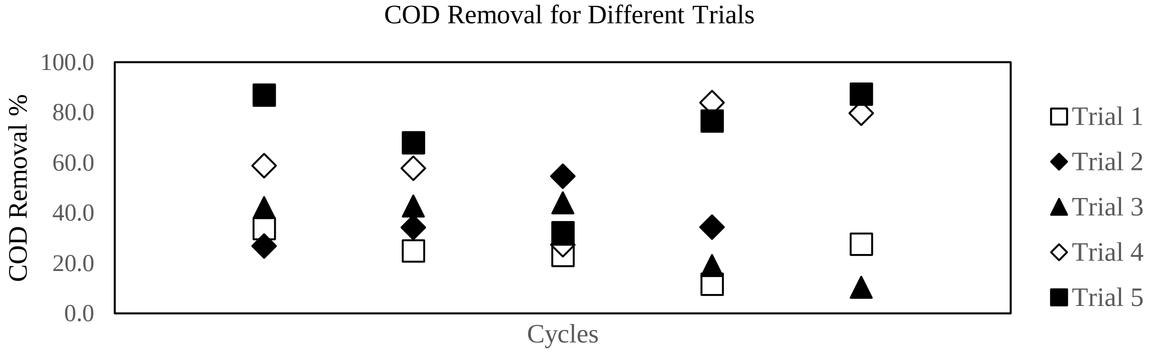


Figure 3: COD removal efficiency for different trials

Textile wastewater had a high color value (8700~8900 Pt-Co Unit). For the first three trials, color removal efficiencies were 56.4%, 65% and 20.6% which were not satisfactory. So, the color value of the effluent was not measured for every cycle. The color removal efficiency increased significantly from the fourth trial. Influent and effluent color and color removal efficiency for the last two trials are shown in figure 4 and figure 5 respectively.

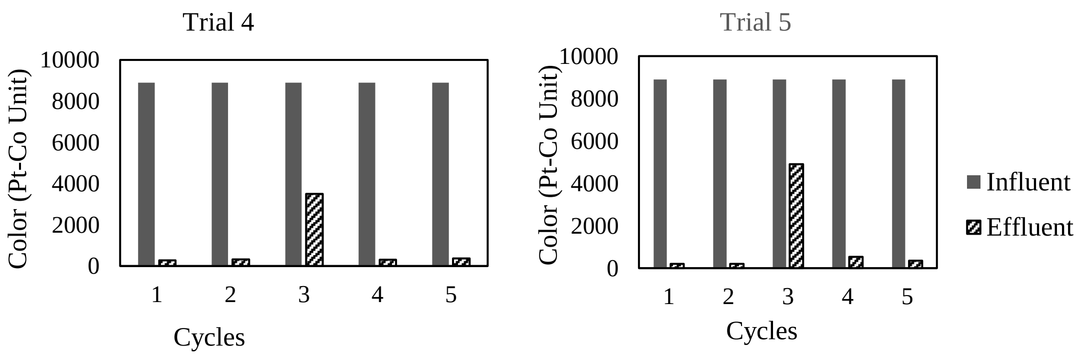


Figure 4: Performance of the reactor in removing color over different cycles of run for different trials where each trial represents different operating conditions

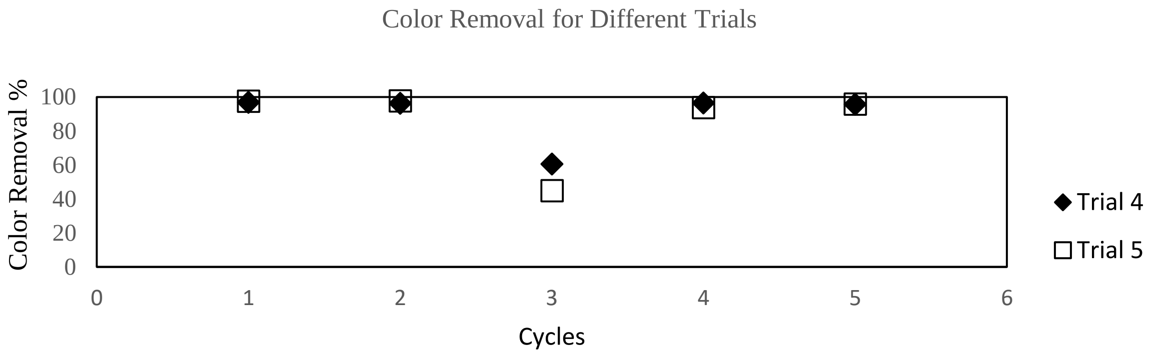


Figure 5: Color removal efficiency for different trials

For the first three trials, COD removal efficiency started to decrease from the fourth cycle (figure 3). In these trials, the generated sludge remained in the reactor which could be affecting the effectiveness of the reactor. So, in the fourth and the fifth trials, sludge was removed after the third cycle of wastewater treatment. In these trials, *Pseudomonas* was dominant in the reactor. Though HRT was comparatively lower compared to the previous trials (~7 hours), high COD and color removal were observed. COD removal for the first two cycles remained around 58% which decreased to 27.3% in the third cycle. Color removal for the first two cycles remained around 96% which decreased to 60.7% in the third cycle. Removing the sludge after the third cycle resulted in 83.8% and 79.6% COD removal and 96.5% and 95.8% color removal for cycles 4 and 5 respectively. Further decreasing HRT from 7 hours to 4 hours in the fifth trial did not affect the performance of the reactor significantly. In trial 5, initially, 86.9% COD removal and 97.6% color removal was observed in cycle 1. Similar to trial 4, removal efficiency decreased in the third cycle (32.1% for COD and 44.9% for color). After removing the sludge, the efficiency of the reactor increased to 76.6% and 87.3% for COD removal and 93.9% and 96% for color removal in cycles 4 and 5 respectively. It can be inferred that the accumulation of sludge had a negative impact on the performance of the reactor. For our setup, removing sludge after every three cycles increased the performance of the reactor.

It has been mentioned earlier that, different bacterial species were found in the reactor depending on the type of food present. The presence of these species can also be correlated with the removal efficiency obtained in the different trials (Figure 6). It can be seen that while *Klebsiella* and *E. coli* were the dominant species in the reactor (trials 1 – 3), the COD removal efficiency did not exceed 54.5%. Though sludge removal improves the efficiency of the reactor and sludge was not removed in trials 1 to 3, it can be envisaged that even with sludge removal we would not expect the removal efficiency to go beyond what we observed in the initial cycles of these trials. On the other hand, in trials 4 and 5, *Pseudomonas* was dominant and due to its efficiency in degrading complex hydrocarbons, we observed higher COD and color removal compared to the previous trials.

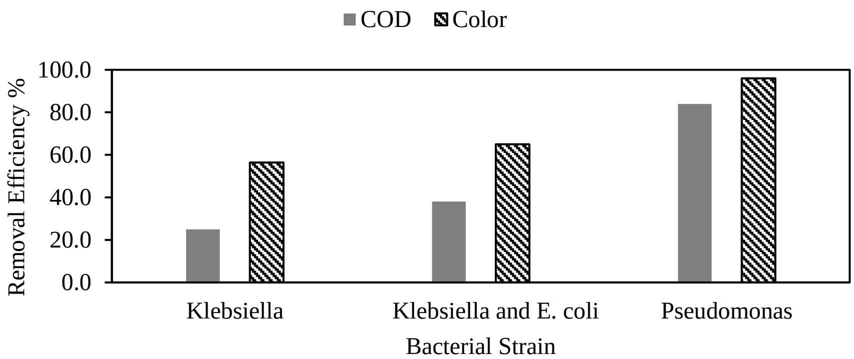


Figure 6: COD and color removal efficiency for different bacterial growths

3.3 BOD Removal

As COD was the main parameter for evaluating the performance of the reactor, BOD was not monitored until significant removal of COD was achieved. Only after achieving more than 80% COD removal, BOD removal was measured. BOD value decreased from 730 mg/L to 52 mg/L and 54 mg/L in the fourth and the fifth trial respectively (removal efficiency 93%, not shown in figure) which are well below the national discharge standard for BOD of textile industry effluent (150 mg/L) according to ECR 1997.

3.4 Comparison with Full-scale UASB ETPs operational in Bangladesh

The performance of the lab-scale HUASB is compared to three other UASB based Full-scale ETPs currently operational in Bangladesh (Table 3). These ETPs have Downflow Hanging Sponge (DHS) unit and aeration processes in addition to UASB unit and high retention time (40 hours HRT for UASB unit). Though the final effluent quality conforms to the discharge limits described in the Environment Conservation Rules (ECR) 1997, the efficiency of the UASB unit in particular in the removal of COD, BOD and color is poor. ETP1 showed the best performance among the operational UASB units where a maximum removal of 66%, 53%, and 50% for COD, BOD, and color respectively was obtained. ETP2 and ETP3 had comparatively stronger wastewater with COD value in the feeding tank of 1075 and 2310 mg/L respectively. However, the removal efficiencies of these two ETPs are considerably lower compared to ETP1. For example, for ETP3, the wastewater from feeding tank is passed through two UASB reactors, each of which had an HRT of 20 hours and in spite of having longer retention time than what we used in our experiments, COD, BOD and color removals are 2.8%, 18%, and 3% respectively. Such low removal efficiencies are very unlikely for a UASB unit. Most probably, the accumulation of sludge is the reason behind the poor performance of the reactor. The UASB unit has been operational for more than a year. But according to the maintenance engineer, the sludge was never removed from the UASB unit which could have reduced the effectiveness of the process. In contrast, the DHS unit of that particular ETP performed better with a removal efficiency of 50%, 61%, and 20.9% for COD, BOD, and color respectively. Our lab-scale HUASB reactor showed better performance than the UASB units of these ETPs. Moreover, in spite of having significantly lower retention time and no additional treatment operation (e.g. aeration), the lab-scale HUASB delivered an end product that was comparable to that of the three ETPs. This indicates that if a Hybrid UASB can be installed in these ETPs, their efficiencies can be increased with concomitant savings in operational costs.

Table 3: Comparison among operational efficiencies of different operational UASB based ETPs in Bangladesh and Lab-scale HUASB (Removal percentages with respect to the concentration in the equalization tank are shown in parentheses)

ETP	Parameter	Equalization Tank	After UASB	After DHS	Outlet
ETP 1(Rashid & Shahid, 2017) **UASB+DHS +Aeration**	Color (Pt-Co Unit)	1264	432(66%)	120(90%)	110(91%)
	COD (mg/L)	428	198(53%)	179(58%)	57(87%)
	BOD (mg/L)	200	99(50%)	69(65%)	22(69%)
ETP 2 **UASB+DHS +Aeration**	Color (Pt-Co Unit)	1320	1100(17%)	1400 (-6%)	660(50%)
	COD (mg/L)	1075	923(14%)	658(39%)	158(85%)
	BOD (mg/L)	496	262(47%)	160(68%)	20(96%)
ETP 3 **UASB+DHS+ Aeration**	Color (Pt-Co Unit)	8900	8600(3%)	6800(24%)	23(99%)
	COD (mg/L)	2310	2246(3%)	1124(51%)	76(97%)
	BOD (mg/L)	733	600(18%)	233(68%)	22(97%)

ETP	Parameter	Equalization Tank	After UASB	After DHS	Outlet
This Study (Lab-scale HUASB)	Color (Pt-Co Unit)	8900	344(96%)	-	-
	COD (mg/L)	2310	293(87%)	-	-
	BOD (mg/L)	733	52(93%)	-	-

4. CONCLUSIONS

UASB reactor generally requires post-treatment for satisfactory effluent quality. It takes almost three to four months for the growth of bacteria granules in UASB when no inert materials are added (Hulshoff Pol et al., 2004). But in hybrid UASB, bacterial biofilm is generated quickly because of the attached growth. For our lab-scale reactor, only two days were needed for the incubation of bacteria. Effectiveness of different bacteria grown in the reactor was evaluated and *Pseudomonas* was found out to be very effective which takes polycyclic aromatic hydrocarbon (PAH) as the main food. After the growth of this bacterium in the reactor, removal efficiency of COD, BOD and color increased significantly. After sludge was taken out, the reactor performance increased. Without further treatment, effluent quality from HUASB, particularly BOD and COD, has been found to conform to the limits for discharging in public sewerage system or irrigated land as prescribed in the national standards. So, with effective bacterial growth and maintenance, the HUASB reactor can be a huge step up from conventional UASB and a suitable alternative for the treatment of textile wastewater.

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