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Performance Evaluation of an Effluent Treatment Plant for Pharmaceutical Effluent with Different Treatment Mechanisms

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Abstract

A multistage effluent treatment plant (ETP) was installed in a pharmaceutical factory in Comilla District, Bangladesh, to treat the discharged effluent from the factory. This study evaluated the treatment performance of the ETP through physical, chemical, and biological treatment processes. The treatment plant consisted of equalization, neutralization, anaerobic followed by aerobic biodegradation, two-stage clarification, reed bed bio-filtration, and post-aeration units. Water quality parameters including pH, turbidity, TDS, TSS, TS, COD and BOD_5 were analyzed at the IUBAT-Environmental Engineering Laboratory. The ultimate removal efficiencies were 100% for turbidity, 97% for TSS, 95% for COD, and 97% for BOD_5. The average reduction ranges for, turbidity, TSS, TS, COD and BOD_5 were 201 FTU to 0 FTU, 512 mg/L to 13 mg/L, 912 mg/L to 530 mg/L, 2034 mg/L to 99 mg/L, and 1126 mg/L to 29 mg/L respectively. The anaerobic treatment unit achieved 1%, 17%, and 37% removal efficiencies for turbidity, COD, and BOD_5, while the aerobic unit achieved 76%, 86%, and 86% removal efficiencies. The chemical treatment process was found effective for TSS and turbidity removal. The Reed Bed System performed well in removing BOD_5, COD, and Turbidity of the effluent. The ETP's final discharge complied with water quality standards set by the Department of Environment, Bangladesh.

Keywords: *Effluent; Aerobic; Anaerobic; Biological; Chemical.*

1 Introduction

Exposure to active pharmaceutical ingredients (APIs) in the environment can lead to adverse impacts on both ecosystems and human well-being. The pollution caused by APIs bears a worldwide danger to the health of the environment and humans, as well as to the achievement of the Sustainable Development Goals (SDG) set by the United Nations (Wilkinson et al., 2019)**.**

Emerging pollutants created by human activities are dispersed into the environment. These emerging pollutants include substances like pharmaceuticals, personal care products, surfactants, plasticizers, and pesticides. These chemicals pose a threat to both human health and the environment. Subsequently, the disposal and treatment of these emerging contaminants have become major concerns in the field of water treatment and reuse. Removal of these chemicals from the effluent in a short time is a very difficult task. Bioremediation plays a crucial role in the treatment of these emerging pollutants (Patel et al., 2020; Wilkinson et al., 2022). As the global population continues to grow, there will be an accompanying increase in the release of these emerging pollutants. The rise in antibiotic-resistant bacteria poses the most significant challenge, as even small concentrations of antibiotics have the potential to foster their development (Nazaret & Aminov, 2014). These bacteria can generate genes that provide them with protection against antibiotics (Rizzo et al., 2013). According to the World Bank's projections, by the year 2050, these antibiotic-resistant bacteria have the potential to cause the deaths of 10 million people annually and drive approximately 28 million people into poverty (Bloom et al., 2017).

The possible toxic discharges from wastewater treatment plants have raised significant concerns regarding the well-being of both humans and the environment (Sanderson et al., 2004; Verlicchi et al., 2012) Implementing advanced water treatment technologies after secondary treatments has the potential to decrease the concentrations of pharmaceuticals present in effluent (Xiao et al., 2019). Within conventional activated sludge processes, pharmaceuticals can be eliminated through various mechanisms such as volatilization, sorption, oxidation, and biodegradation. These physical, chemical, and biological processes contribute to the removal of pharmaceutical compounds (Li & Zhang, 2010). Biodegradation is widely recognized as the primary mechanism for the attenuation of pharmaceutical compounds among various processes. It is considered the foremost process dependable for the degradation and reduction of pharmaceuticals in the environment (Ericson, 2010; Kim et al., 2005).

The Effluent Treatment Plant (ETP) being discussed is located in Chauddagram, Comilla, Bangladesh. This ETP was designed to handle approximately 1.5 cubic meters of wastewater per hour, generated from various pharmaceutical production units within the factory. The wastewater is directly discharged into the ETP for treatment before discharge into the environment. It is important to note that effluent originating from the antibiotic units undergoes pretreatment following the standard protocol established by the company. This pretreatment process ensures that the effluent from the antibiotic units meets the requirements before being discharged into the ETP for further treatment. This additional step highlights the company's commitment to maintaining high standards and promoting environmental sustainability.

2 Materials and Method

The study was conducted over a consecutive three-month period (September 2020 to December 2020), during which wastewater samples were collected periodically from all the treatment units of the studied effluent treatment plant. The collection, transportation, preservation, and laboratory analysis of the samples followed the Standard Method (APHA, 2017). All the tests had been conducted in the Environmental Engineering Laboratory of IUBAT, except for dissolved oxygen and pH, which were measured on-site. The treatment process flow diagram and the sample collection points have been shown in Figure-1 to indicate the actions of different units of the ETP.

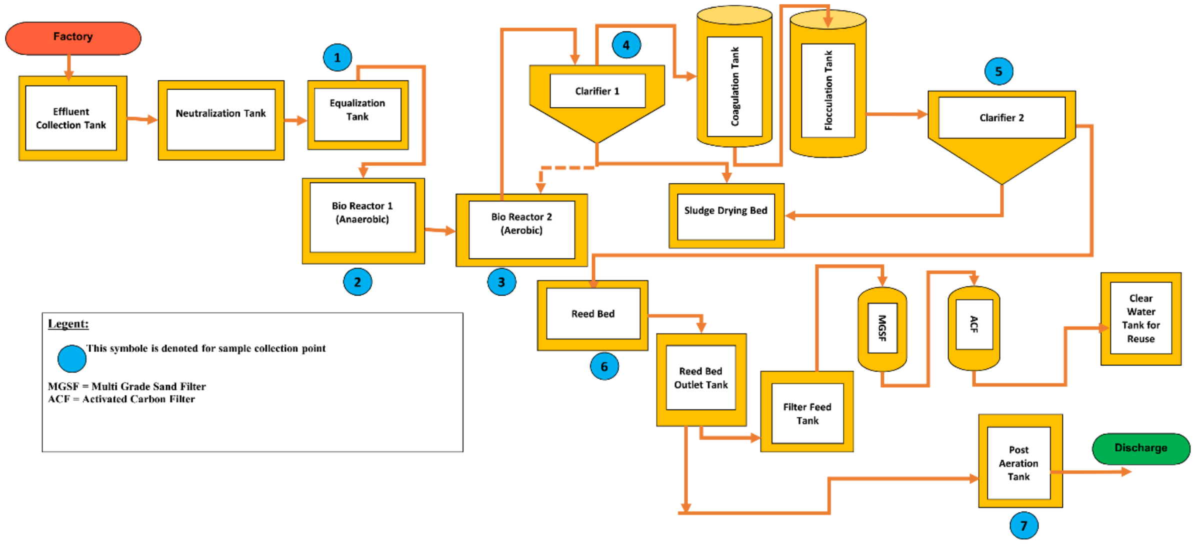

Figure 1. Process flow diagram with sample collection points of the ETP

The equalization tank serves as the primary treatment unit, receiving effluent continuously throughout the day. To maintain the optimal pH level, an automated pH adjustment system had been integrated into the equalization tank. The ETP employs a two-stage biological treatment process, starting with the up-flow anaerobic sludge blanket (UASB) system and followed by the activated sludge process. Initially, the effluent from the equalization tank is pumped into Bioreactor-1, where anaerobic biodegradation takes place through the UASB process. Subsequently, the partially treated effluent is directed to Bioreactor-2, where further biodegradation of excess organic matter occurs with the assistance of aerobic bacteria. To clarify the aerated effluent of Bioreactor-2, a plane sedimentation process is employed within Clrifier-1. The settled sludge is then returned to Bioreactor-2 to maintain the desired concentration of biomass in the reactor. The combined action of Bioreactor-2 and Clrifier-1 is termed an activated sludge process.

The supernatant of Clarifier-1 is directed to Clarifier-2 to remove any remaining unsettled colloidal particles using a chemical sedimentation system i.e. coagulation and flocculation. Any excess sludge from Clarifier-1 and all sludge from Clarifier-2 are discharged into the Sludge Drying Bed, where dewatering occurs before disposal. The clarified effluent undergoes additional polishing in the Reed Bed unit followed by a Post Aeration system, which involves both physical and biological processes. This stage ensures that the effluent meets the required standards for parameters, as mandated by local effluent discharge regulations.

Several key effluent quality indicators (KEQI) were assessed in different units of the ETP. These parameters include pH, turbidity, total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), mixed liquor suspended solids (MLSS), sludge volume index (SVI), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and dissolved oxygen (DO). Each of these parameters was carefully measured and analyzed to evaluate the performance and effectiveness of the treatment process at various stages of the ETP. The utilization of these parameters provides valuable insights into the overall water quality and the efficiency of the treatment system. In the different treatment units of the Effluent Treatment Plant, various parameters were tested to assess water quality and evaluate the effectiveness of the treatment process. The parameters that were tested are mentioned in Table 1.

Table 1. Effluent Parameters Tested in Different Units.

Unit No	Name of the Treatment Unit	Effluent Parameters
1	Equalization Tank (Eqn. T)	pH, Turbidity, TDS, TSS, TS, COD and BOD_5
2	Bioreactor-1 (BR-1)	pH, Turbidity, TDS, TSS, TS, COD and BOD_5
3	Bioreactor-2 (BR-2)	pH, Turbidity, SVI, TDS, MLSS, TS, and DO
4	Clarifier-1 (Clr-1)	pH, Turbidity, TDS, TSS, TS, COD and BOD_5
5	Clarifier-2 (Clr-2)	pH, Turbidity, TDS, TSS, TS, COD and BOD_5
6	Reed Bed (RB)	pH, Turbidity, TDS, TSS, TS, COD and BOD_5
7	Post Aeration Tank (PAT)	pH, Turbidity, TDS, TSS, TS, DO, COD and BOD_5

During the research period, water quality data from the various units of the ETP were collected five times. These data points were then accumulated and prepared for statistical analysis using computer software. In this case, Microsoft Excel (2016) was utilized to perform the data analysis and generate the necessary inferences. By inputting the collected data into Excel, various analytical techniques and statistical calculations were applied to evaluate the performance of different treatment units within the ETP. By employing statistical analysis, the study was able to assess the performance of the different treatment units in the ETP and derive valuable insights regarding water quality, treatment efficiency and compliance with relevant standards or regulations.

3 Results and Discussion

The laboratory test results of different treatment units of the ETP in the study period have been summarized in Table 2. The results show that the removal of different pollutants in different units had some sequences. There was some significant variation of results observed in individual processes. There are some key effluent quality indicators (KEQI) which indicate the performance of the treatment units. According to the characteristics of the effluent and treatment process Turbidity, TDS, TSS, COD and BOD are considered as KEQI to evaluate the studied ETP.

Table 2. Summary of the Effluent Test Results from Different Treatment Units.

Water Quality Parameters	Treatment Units (Mean ± SD)						
	1. Eqn. T	2. BR-1	3. BR-2	4. Clr-1	5. Clr-1	6. RB	7. PAT
pH	6.48±0.42	6.28±0.21	7.03±0.65	7.20±0.52	6.33±0.54	6.99±0.43	7.78±0.43
Turbidity (FTU)	201±101	199±94		47±29	0.49±0.17	0.09±0.2	0.00
TDS (mg/l)	400±33	398±76		410±82	518±78	522±75	522±75
TSS (mg/l)	512±272	480±136	4346±1481	68±50	26±15	20±12	13±6
TS (mg/l)	912±272	878±81		478±127	544±85	538±76	530±79
COD (mg/l)	2034±441	1691±275		238±97	145±36	104±23	99±30
BOD_5 (mg/l)	1126±224	708±245		99±62	40±20	35±14	29±7
SVI (ml/g)			58±13				

Turbidity: The raw influent bears a high amount of turbidity which is 201±101 FTU due to the presence of colloidal particles of pharmaceutical products. But through several treatments, it decreases significantly and gradually. It had been observed that after aerobic biodegradation in Bioreactor-2 and clarification, it reduces significantly. It was also evident that chemical treatment with coagulation and flocculation followed by clarification can remove most of the turbidity of water. On the other hand, a reed bed also plays a vital role to remove turbidity. The discharged effluent had a turbidity level of 0 FTU.

TDS: The studied treatment system could not remove dissolved solids from the effluent. On the other hand, TDS increased after chemical treatment due to the addition of coagulant and flocculent. It increased from 400±33 mg/l to 522±75 mg/l.

TSS: The suspended solid concentration in the influent was 512±272 mg/l. It slightly decreased when it discharged from the Bioreacrtor-1 but a dramatic increment was observed in the Bioreactor-2 due to the presence of biomass in the aeration tank. The suspended solids in the aeration tank are considered mixed liquor suspended solids (MLSS) and their concentration was found as 4346±1481 mg/l. Further, it is decreased abruptly when effluent is clarified both in physical and chemical clarification systems. The TSS value gradually decreased and 13±6 mg/l was found in the final effluent discharge point.

COD: The concentration of chemical oxygen demand in the influent was found as 2034±441 mg/l and decreased to 1691±275 mg/l when it was discharged from Bioreactor-1 and reduced to 238±97 mg/l when it is treated in Bioreactor-2 and clarified. Further COD value decreased significantly when it was chemically clarified and become 145±36 mg/l. It is also reduced slightly through the Reed Bed and Post Aeration system. The COD concentration was found as 99±30 mg/l at the outlet of the Post Aeration Tank.

BOD: The biochemical oxygen demand reduction characteristics of the effluent were also similar to the COD reduction process. The BOD_5 of the raw effluent was found as 1126±224 mg/l. It reduced to 708±245 mg/l then 99±62 mg/l and 40±20 mg/l in Bioreactor-1 then Bioreactor-2 followed by clarification and chemical clarification respectively. It also reduced slightly in Reed Bed and the BOD5 concentration was found as 29±7 mg/l in the final effluent discharge point at the Post Aeration Tank.

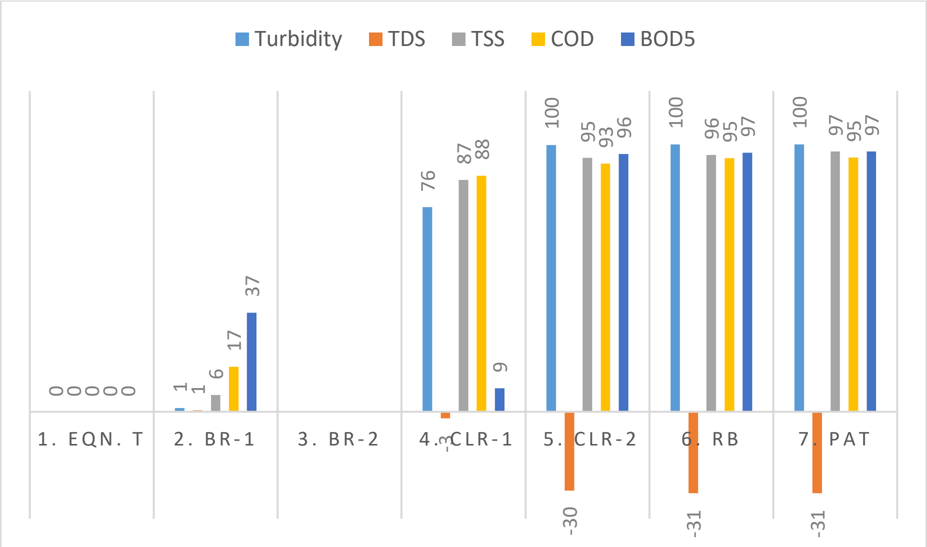

Figure 2. Pollution Retention Percentage in Different Units from Raw Effluent

Figure-2 demonstrates the gradual removal of pollutants during the treatment process. It was observed that the majority of pollutants were effectively removed at the 5th stage of treatment in Clarifier-2, except for TDS. The concentration of TDS experienced a significant increase due to the introduction of chemicals during the coagulation and flocculation processes. However, at the final stage of treatment, it was observed that the water became free of turbidity, with 97% removal of TSS, 95% removal of COD, and 97% removal of BOD_5 from the initial effluent. Although there was a 31% increase in TDS compared to the influent water, it remained within the acceptable limit.

Figure-3 demonstrates notable improvements in wastewater treatment by the individual treatment units. Bioreactor-1, utilizing the UASB technic, achieved a reduction of 17% in COD and 37% in BOD_5. Conversely, Clrifier-1, employing the activated sludge process (aerobic biodegradation followed by clarification), exhibited impressive removal rates of 86% for TSS, COD, and BOD_5. Turbidity removal efficiency in Clarifier-1 reached 76%, while Clarifier-2 surpassed expectations with a remarkable 99% efficiency. Clrifier-2 also demonstrated efficiency rates of 62%, 39%, and 60% for TSS, COD, and BOD_5, respectively. The Reed Bed unit proved its effectiveness by removing 82% turbidity, 23% TSS, 28% COD, and 12% BOD load. The presence of macrophytes within the system played a crucial role by providing oxygen for microbial proliferation, facilitating the breakdown of complex organic substances, and aiding in the absorption of certain nutrients and heavy metals present in the wastewater. The primary mechanisms responsible for pollutant removal include biochemical transformation, adsorption, precipitation, and plant uptake (K & Chinnusamy, 2019). Additionally, the Post Aeration Tank not only serves the purpose of increasing dissolved oxygen level in the effluent but also contributes to a significant reduction in pollution load to some extent.

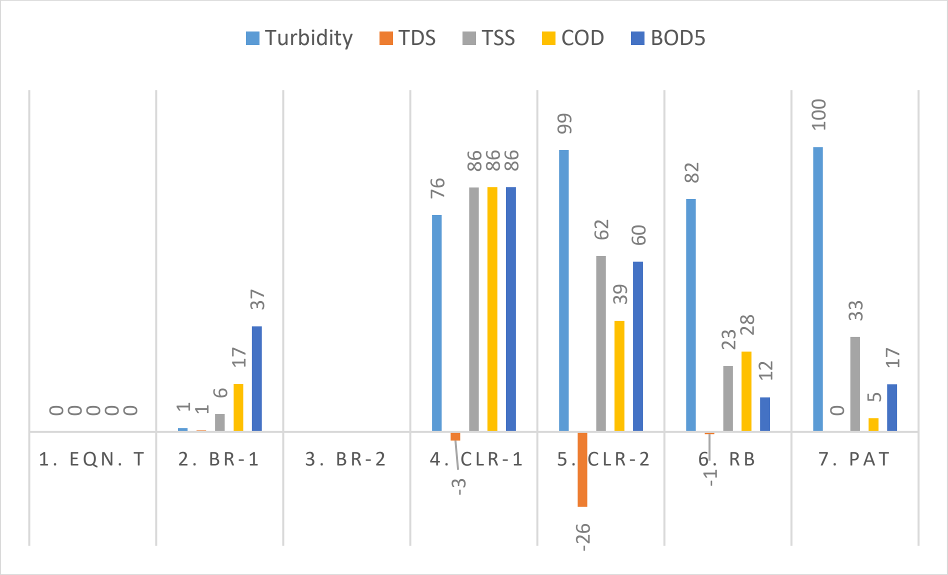

Figure 3. Pollution Removal Percentage in Individual Units

During the study, it was observed that Bioreactor-1 can remove (2034-1691) = 343 mg/l of COD. Assuming the plant operates at a flow rate of 1.5 m^3/hr for 20 hours per day, the biogas production rate can be calculated based on the average COD load of the wastewater, as mentioned by Tchobanoglous et al., 2014. The following equation can be derived at a temperature of 25°C.

$$\begin{aligned}\text{Methane Production Rate} &= \text{COD } (g/m^3)/\text{day} \times 382 \times 10^{-6} \\ &= m^3\ /\text{day} \\ &= 1.5 \times 20 \times 343 \times 382 \times 10^{-6}\ m^3/\text{day} \\ &= 3.93\ m^3/\text{day}\end{aligned}$$

According to a study by Dai et al., 2019, it was found that 1 gram of COD can generate approximately 16.1 kilojoules (kJ) of energy. Based on this, the studied ETP could produce around 166 megajoules (MJ) of energy per day,

Furthermore, the sludge from Bioreactor-2 was characterized as compact, as indicated by the sludge volume index (SVI) value of 58±13 ml/g. According to Kemmer, 1987, sludge with an SVI value below 100 ml/g is considered compact. This suggests that the sludge compactly settles in the clarifier, without any bulking occurring.

The effluent treatment plant is reported to meet the water quality standards set by the Department of Environment (DoE) according to the guidelines of the Environmental Conservation Rules (ECR, 1997). The treatment units within the plant were found to be effective to some extent in achieving this standard.

4. Conclusion:

After conducting a three-month continuous study on the effluent treatment plant, it has been identified that the final discharge meets all the parameters guided by the Department of Environment (DoE). The performance comparison between Bioreactor-1 and Bioreactor-2, based on water quality test reports, indicates that Bioreactor-2 exhibits a higher efficiency in removing organic pollutants compared to Bioreactor-1. Therefore, it can be concluded that aerobic treatment is more effective than anaerobic biodegradation for pharmaceutical effluent with the same detention time. Regarding the clarification process, chemical sedimentation has proven to be more efficient than plain sedimentation in removing BOD, COD, and TSS. However, it should be noted that the TDS levels increased significantly during the chemical treatment process. Additionally, it was observed that the Reed Bed system is primarily effective in removing the turbidity of water.

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