Journal of Asian Scientific Research
ISSN(e): 2223-1331
ISSN(p): 2226-5724
DOI: 10.18488/journal.2.2020.103.121.130
Vol. 10, No. 3, 121-130.

URL: www.aessweb.com

PROCESS DESIGN AND PHYSICOCHEMICAL CHARACTERIZATION OF EXTENDED AERATION ACTIVATED SLUDGE TREATMENT PLANT: A CASE STUDY

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Article History
Received: 7 February 2020
Revised: 10 March 2020
Accepted: 14 April 2020
Published: 18 May 2020

Keywords
Extended aeration activated sludge
Physiochemical parameters
Process design
Removal efficiency
Sewage treatment plant
UiTM Sarawak Branch.

ABSTRACT

The discharge of untreated wastewater to the environment causes adverse environmental problems. In this regard, feasible wastewater treatment system must be designed and operated to reduce the pollutant load and to safeguard the public health. The efficiency of a sewage treatment plant located in a residential college in UiTM Sarawak Branch, Samarahan Campus was examined in terms of process design and physiochemical parameters. Physiochemical parameters included pH, temperature, turbidity, chemical oxygen demand (COD) and suspended solids (SS) from raw influent and treated effluent were investigated using the Standard Methods. Removal efficiency of these parameters was also determined to evaluate the performance of the plant. The findings revealed that overall performance of the plant was satisfactory. All physiochemical parameters of the treated effluent complied with the requirements of Standard B, Environmental Quality (Sewage) Regulations 2009 except SS. The lowest concentration of turbidity and COD in the effluent was reported in the second week of the sampling period. The findings obtained were due to the low influent loading during the semester break where the number of students resided in the college was very minimal. The removal efficiencies of turbidity and COD were found to be 65% and 83%, respectively. A non-compliance SS requires special attention to enhance the efficiency and to maintain the good operation of the system to meet the stipulated standards.

Contribution/ Originality: This study contributes in the existing literature about the design process and physiochemical characterization of the extended aeration activated sludge treatment system. The findings of this study are beneficial for the plant operator to achieve optimum operation of the system to ensure full compliance of the standards and preserving environment.

1. INTRODUCTION

In response to growing population and urbanization, the world's water demand also increasing which eventually produce large amount of municipal wastewater. Domestic sewage or untreated sanitary waste is a subset of wastewater. It constitutes approximately 99% water and the remaining 0.1% is considered as water impurity which contains organic and inorganic materials, suspended and dissolved solids and microorganisms [1]. The discharge of untreated sewage to water resources may harm water ecosystem and can cause water-borne diseases if it is consumed by human. Given the serious impacts of untreated sewage to environment and human, the domestic sewage needs to be treated by a proper sewage treatment mechanism. Sewage treatment is the method that are designed to simulate the natural treatment processes to reduce pollutant load to a level that nature can handle [2]. There are many processes designs available to treat wastewater, however the selection preference is commonly based on few factors such as operational cost, land availability, easy to function, low-maintenance and manage comply to effluent standards. Biological treatment process is the heart of the sewage treatment plant (STP) because it is the process where the dissolved solid and the non-settleable organic materials are removed by living organisms. The extended aeration (EA) system is one of the biological treatment processes recommended by the National Water Services Commission (SPAN). This system is categorized as suspended growth process because high population of active microorganisms persist in the sewage suspension and this mixture is called mixed liquor suspended solids (MLSS). EA system produces high MLSS concentration and low sludge wastage due to its advantage of having long hydraulic holding times that allows the plant to operate well [3].

Performance of sewage treatment plant is measured in terms of effluent quality which must be in accordance to the Environmental Quality Act (EQA) 1974. Effluent quality can be measured based on several domestic sewage parameters including physical, chemical and biological characteristics. Turbidity in water is affected by suspended and colloidal matters such as soil, sediment and finely divided organic-inorganic matters. Turbidity refers to the optical property that causes light to be distributed and absorbed [4]. Suspended solids (SS) is a fragment of organic and inorganic solids that are non-filterable. pH of the wastewater is used to measure the hydrogen ion activity in the effluent wastewater which has a profound effect on the rate of microbial growth. Abnormal or irregular pH in biological treatment processes causes a significant decrease in the rate of organic compounds removal from the environment, which consequently affects BOD measurements [1]. Temperature affects the rate of reaction in the most treatment processes. Chemical oxygen demand (COD) gives the measure of oxygen required for chemical oxidation stabilise the carbonaceous organic matter [2].

As concerns towards the environmental impact from wastewater treatment plant increase, profuse research has been conducted to evaluate the performance of the STP for optimizing its processes. The performance evaluation is a fundamental knowledge on the functional performance to identify future enhancement of the process [5]. Therefore, this study aims to explore the process design of an extended aeration activated sludge treatment plant in UiTM Sarawak, Samarahan Campus. Physiochemical parameters included pH, temperature, turbidity, chemical oxygen demand (COD) and suspended solids (SS) from raw influent and treated effluent were investigated using the Standard Methods. Subsequently, the removal efficiency of the measured parameters was determined to assess the overall performance of the plant.

2. MATERIAL AND METHODS

Figure 1 shows the STP in the study area located at Universiti Teknologi MARA (UiTM), Sarawak Branch, Samarahan Campus. Ground observation was conducted to inspect the performance requirement of the STP whether the system functioned in order to operate as required. Subsequently, influent sewage from sump pump and effluent from the final discharge were taken periodically every three days in five consecutive weeks to monitor the performance of the process in the plant. Five physiochemical parameters were analysed including pH, temperature, turbidity, chemical oxygen demand (COD) and suspended solids (SS). The type of samples is grab samples where they were collected at specific time and place to represent only the composition of the source at that particular time and point. All samples were preserved in a cool box at temperature 1°C – 4°C before transported to the laboratory.

Figure-1. Location of the sewage treatment plant in UiTM Sarawak Branch, Samarahan Campus

2.1. In-Situ Measurement

In-situ measurement involved physical parameters such as turbidity, temperature and pH were measured by using portable instruments. The instrument used for measuring turbidity was turbidimeter HACH DR900. pH value and temperature were measured using Extech EX800. These parameters were determined immediately after the sample was taken. All samples were agitated gently before analyses to ensure a representative measurement. These parameters were measured immediately because they might change significantly in a matter of minutes [4]. All instruments were calibrated prior to use.

2.2. Laboratory Analyses

All the laboratory analyses were conducted according to the Standard Methods for the Examination of Water and Wastewater [4].

2.2.1. Chemical Oxygen Demand

The test was carried out in accordance to USEPA reactor digestion method by using HACH spectrophotometer. 100mL of sample was homogenized first before being tested. The spectrophotometer was preheated at 150°C and 2mL of sample was added to the COD digestion reagent vials. Blank sample was also prepared using the same method. The samples were then heated for two hours. The vials were inverted several times after 20 minutes of cooling time prior to the measurement of COD.

2.2.2. Suspended Solids

Examination of suspended solids analysis was carried out using gravimetric analysis. The initial weight of filter paper was noted after drying in the oven at 100°C-105°C for 1 hour. A 10 mL volume of the water sample was filtered through a Whatman GF/F glass fibre filter (nominal pore size 0.7 µm). The residue was desiccated to constant weight before weighing. The suspended solids content was analysed by using Equation 1.

$$\text{Suspended Solids}\left(\frac{mg}{L}\right) = \frac{(A - B) \times 1000}{mL\ sample} \qquad (1)$$

Where A = the weight of filter paper + dried residue (mg), B = weight of initial filter paper (g) and the volume of sample is 10 mL.

2.3. Removal Efficiency of a Pollutant

The removal efficiency of a pollutant in the treatment stage is given by the formula in the Equation 2 adopted from Sterling [1].

$$E = \frac{C_0 - C_E}{C_0} \times 100 \qquad (2)$$

Where E = removal efficiency (%), C_0 = influent concentration of the pollutant (mg/L), C_e = effluent concentration.

3. RESULTS AND DISCUSSION

3.1. Process Design of the Extended Aeration Activated Sludge Treatment Plant

The schematic diagram of the process flow is shown in Figure 2. The influent sewage was coming from the residential college in UiTM Sarawak Branch, Samarahan Campus. This treatment plant was classified as Class 4 in accordance to the design capacity that catered for 2,000 PE which begun the operation since more than 20 years ago. The treatment plant was fully enclosed with concrete and employed extended aeration activated sludge because it offered greater process stability and less potential for generating odours [3]. Enclosed treatment plant is suitable to be placed in the vicinity of residential college because it is good for aesthetic, noise and volatile organic compound (VOC) control. Institutional area is a sensitive area which noise should be minimised to the lowest possible level. The maximum allowable sound level is 50 dBA during daytime and 40 dBA during night time as stipulated in The Planning Guidelines for Environmental Noise Limits and Control, Department of Environment, Ministry of Natural Resources and Environment Malaysia, 2007.

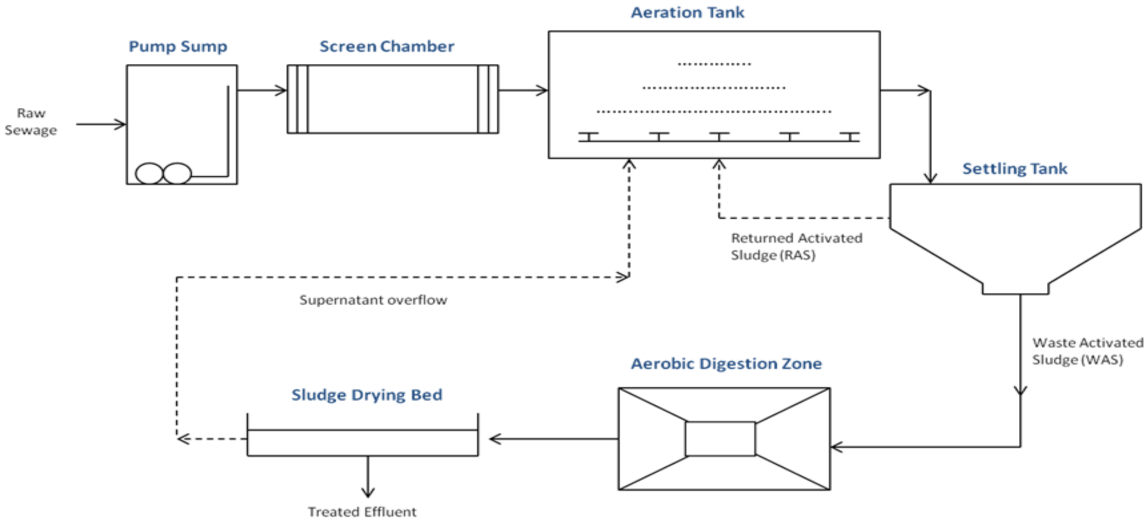

Figure-2. Schematic diagram of the process flow in the extended aeration activated sludge treatment plant.

The characteristics of the influent influence the types of processes to be used and the requirement for their proper operation. The process starts from the raw domestic wastewater is channelled into the primary screen where the mechanical coarse was installed to separate coarse solid materials such as rags, papers, wood and plastic. It is important to remove any physical objects that may cause maintenance or functioning problems in the treatment operations and the ancillary systems [6]. The screened sewage inside wet well will then be lifted up subsequently to secondary screen by a set of raw sewage pumps. Fine screen chamber is used to further trap finer foreign matters [7].

The extended aeration systems do not require a primary clarifier because it has a relatively low sludge yield due to extended sludge ages and can be designed to provide nitrification [8]. The main function of the aeration tank is to maintain high population of microbes. The sewage is aerated over a long period of time using air diffuser which resulted in sewage removal by the active microorganisms grow during the process [3]. The diffuser air systems comprise of air pipeline, blower, diffusers, diffuser holder, sealing gasket, air control orifice and retaining device installed in the aeration zone. Identical mixing can be achieved by proper employment of diffusers on the tank floor. Foams in the aeration tank produced by unnecessary influx of detergents from toilet may cause imbalance in the aeration tank [4].

The MLSS from the aeration tank then is passed to the settling tank where the microbes are made to remain at the bottom by sedimentation. It is used to remove solid particulates or suspended solids from liquid for clarification. The design of the clarifier in this treatment plant is rectangular clarifier which has several advantages over circular clarifier such as less land required, lower in capital cost, simpler and cheaper pipe work layout and also pumping necessity compared to circular clarifier [9]. The settling tank is unmechanized clarifier where the bottom of the tank is shaped like a funnel with a sheer slope. Air-lift pump in the settling tank is installed to collect sludge. The sludge slowly settles towards bottom and slides down the slope to collect at the lowest point of the funnel-shaped bottom [9].

The combination of the aeration tank, the settling tank and the sludge recirculation constitutes an activated sludge biological treatment system. Sludge recirculation from the settling tank to the aeration tank is important to remove excess microbes from the system at regular intervals. The ideal anticipated age of the microbes is between 25 to 30 days. Sludge recirculation rates are typically between 50% to 100% of the throughput rate of sewage in the STP [3]. Overflow water from the clarifier is gathered in an aerobic digestion zone. Some of the settled microorganisms are returned to the biological treatment system in aeration tank to maintain the MLSS concentration. An aerated aerobic digestion zone is provided to prevent the sludge from turning septic. Aerobic digestion process is a decay process worked under low dissolved oxygen conditions ranging typically between 0.5 to 1.0 mg/L. Study by Woo [10] concluded that the keys to the sludge sustainability of an aerobic digestion process are properly designed aeration and mixing system.

Finally, the treated sludge is channeled to sludge drying bed for sludge dewatering. It involves natural way of drying. Tropical climatic condition and easy operation is one of the main factors of the selection method. Supernatant overflow from the underdrains bed are returned back to the aeration tank for further treatment. Dry sludge is collected periodically by the local authority for safe disposal back to the environment. Clear supernatant or treated effluent is discharged to the nearby drain through v-notch plate at the outlet to control the effluent flow rate. The STP is conveniently located near to receiving water course to discharge the treated effluent.

3.2. pH

The pH of wastewater samples as shown in Figure 3 is in compliance with the Malaysian Standard B which has prescribed the maximum permissible limit of pH ranges between 5.5 and 9.0. The pH of raw sewage was generally in the range of 5.5 to 8.0 [2]. Decomposition of organic matter might lower the pH as can be seen in Figure 3. Acidic or basic conditions modify the structure of the microbes and stop the growth. However, some microbes' systems can tolerate pH and will thrive in acidic and basic environments [11]. In the extended aeration system, the nitrification process occurs naturally. As the nitrification process reduces the HCO^{3-} level and increases the H_2CO^3 level, the pH would tend to decrease [1]. The results showed that the treatment plant has optimum pH value for the nitrification process.

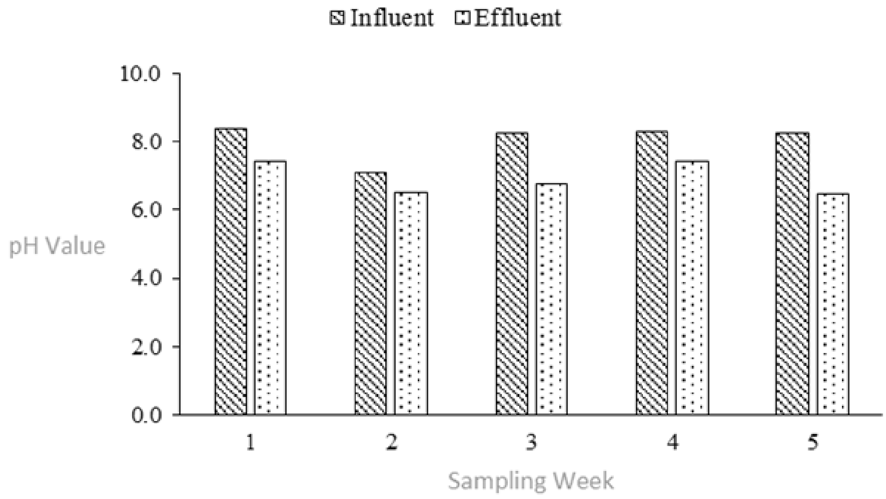

Figure-3. pH value of the influent and the effluent during the sampling period.

3.3. Temperature

Figure 4 shows the temperature of the wastewater samples. The results indicated that all the influent and the effluent wastewater were far below the maximum permissible limit of temperature as stipulated by the regulation. Temperate country like Malaysia which has stable ambient temperature throughout the year, influenced the results obtained. All samples were collected during sunny days. Wastewater temperature is important for biological process as temperature affects the microbial growth. The optimum temperatures for wastewater treatment range from 25°C to 35°C. Biological activity accelerates in warm temperatures but extreme hot or cold may impede treatment process [1]. Thus, temperature in this treatment plant was in the ideal condition for its performance.

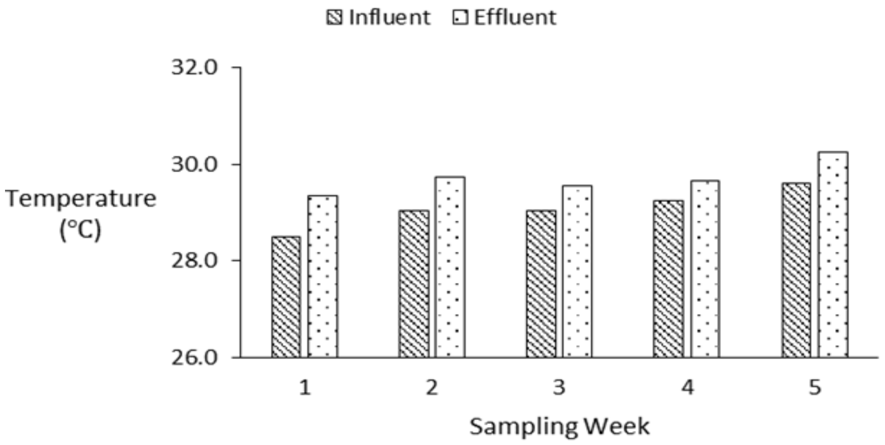

Figure-4. Temperature of the influent and effluent during the sampling period.

3.4. Turbidity

Substantial removal of turbidity can be seen after treatment process as indicated in Figure 5. Week 4 and 5 recorded high turbidity in the influent which might be due to seasonal effect such as heavy rain. However, the turbidity of effluent in all weeks were satisfactory. The highest turbidity removal was recorded during the second week with 95.76% removal efficiency. It was attributed to the low influent loading during the semester break where the majority of the students returned home. Numerous studies have investigated the use of biocoagulant from natural resources to reduce turbidity and TSS due to their efficiency, abundant source, cheap price and biodegradability [12-14]. The use of alum in the water treatment plant in Malaysia is the most common due to its cost-efficiency. However, in this STP, the coagulation and the flocculation processes occurred naturally.

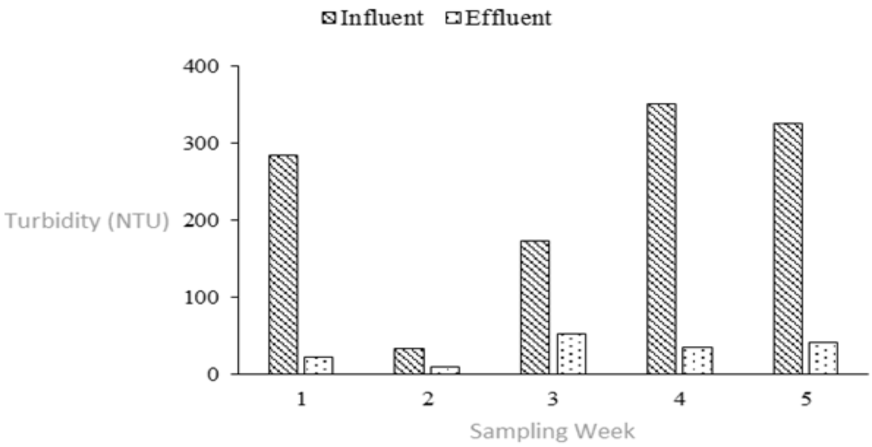

Figure-5. Turbidity of the influent and effluent during the sampling period.

3.5. Chemical Oxygen Demand (COD)

The influent values of COD in this STP was complied with the design influent values of 500 mg/L as mentioned in the Technical Specification Standard Sewage Treatment Plant for Extended Aeration (150 – 5000 PE) published by SPAN. The COD removal was inconsistent throughout the samplings. The lowest COD reading was recorded during the second week due to the low influent loading as a result of low occupancy in the college during the semester break as shown in Figure 6. All COD concentrations detected after the treatment process were far below the Standard B of 200 mg/L maximum permissible limit. COD test is crucial to test the effectiveness of the biological process in the treatment plant. A great variety of microorganisms such as bacteria, protozoa and fungi take part in the biological process. Effective contact between these organisms and the organic matters contained in the sewage of the treatment system helps to culture good environment besides maintains favourable conditions such as temperature, pH and contact time [1].

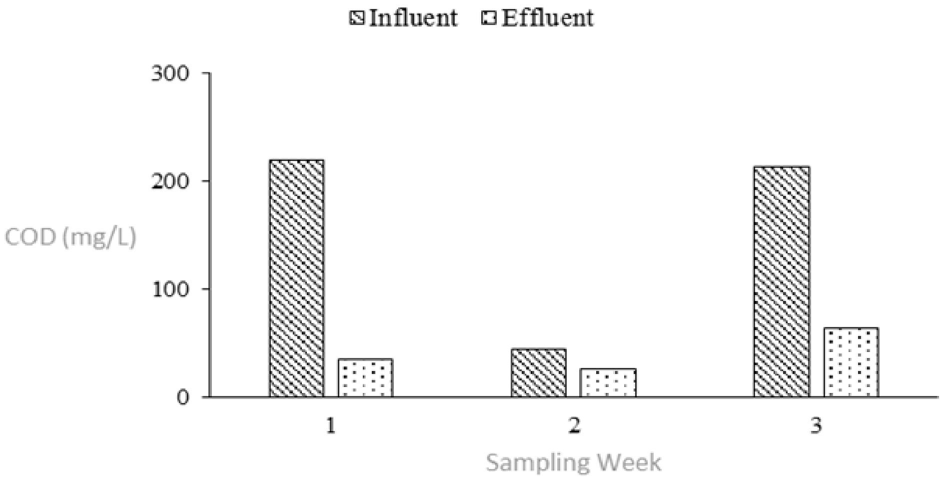

Figure-6. COD of the influent and effluent during the sampling period

3.6. Suspended Solids (SS)

The chief SS content in the influent was obtained during the first week of sampling period which reached more than 600 mg/L. According to SPAN [11] the limit of the design influent values for SS is 300 mg/L. The highest SS concentration in the treated effluent was 280 mg/L which was recorded during the fourth week while the lowest reading about 122 mg/L was obtained during the second week as illustrated in the Figure 7. Biological treatment removed major pollutants such as BOD and SS. The removal of SS throughout the treatment plant process was not sufficient because all the SS effluent readings exceeded the Standard B effluent standard which was set at 100 mg/L. The reason for high SS was due to high influent SS concentration which caused difficult removal of SS in the treatment process. In addition, no chemical coagulant was added to the sedimentation system for aiding coagulation and flocculation processes.

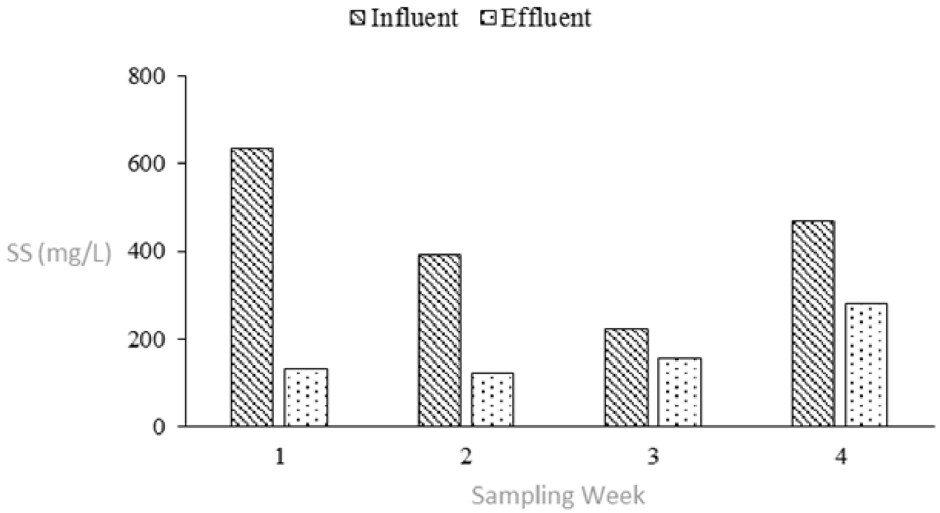

Figure-7. SS of the influent and effluent during the sampling period.

3.7. *Removal Efficiency of Physiochemical Parameters*

The removal of undesired pollutants during treatment processes aims to reach the required quality or discharge standard is associated with the concepts of treatment efficiency [1]. The treatment efficiency of the overall physiochemical parameters examined in this study is summarized in Table 1. The physiochemical parameters in this study were generally removed during preliminary, primary and secondary treatments.

Table-1. Removal efficiency of physiochemical parameters in STP.

Parameter	Removal Efficiency	Compliance to the Standard
pH	na	Yes
Temperature	na	Yes
Turbidity	83%	Yes
Chemical oxygen demand	65%	Yes
Suspended solids	55%	No

Biological wastewater treatment is greatly influenced by climate. Since Malaysia is a temperate country, extended aeration activated sludge method is a suitable treatment system. pH and temperature in the treatment plant were in the optimum range of the process performance. The study recorded the biological treatment in the STP was effective in removing up to 65% of COD. COD was removed in the primary treatment and further reduction in the secondary treatment. The highest removal efficiency was reported for turbidity which can reached approximately 83%. Efficient preliminary and primary treatments such as sedimentation process in removing coarse and settleable solids attributed to high removal of turbidity. Although suspended solids have been removed more than 55% after the treatment process, it still did not comply with the Standard B of the EQA regulation. According to Sperling [1] 60% to 70% and 65% to 95% of suspended solids will be removed in primary and secondary treatments respectively. Findings from this study found that the removal efficiency of SS was inadequate. The STP managing unit can consider to enhance the treatment process by adding suitable coagulants. A non-compliance SS requires special attention to enhance the efficiency and to maintain the good operation of the system to meet the stipulated standards and in turn preserve the intact environment.

4. CONCLUSIONS

This paper presents the efficiency of an extended aeration activated sludge treatment plant in UiTM Sarawak in terms of process design and physiochemical characterization. The overall performance of the plant was satisfactory and the individual unit of the treatment process ran well. All physiochemical parameters of the treated effluent complied with the requirements of Standard B, Environmental Quality (Sewage) Regulations 2009 except SS. The lowest concentrations of turbidity and COD in the effluent were during the second week of the sampling period. The results obtained were due to the low influent loading during the semester break where the number of students resided in the college was very minimal. The removal efficiencies of turbidity and COD were found to be 65% and 83%, respectively. A non-compliance SS requires special attention to enhance the efficiency and to maintain the good operation of the system to meet the stipulated standards. This study also proposed for better performance evaluation by analysing more parameters including biological indicators and using green index as the new quantitative environmental performance indicator for wastewater treatment process.

Funding: This study was supported by the Universiti Teknologi MARA (UiTM) Sarawak with the research grants of Dana Kecemerlangan UiTM Sarawak 2018 with file number: 600-RMU/DANA/ST 5/3 (12/2018).
Competing Interests: The authors declare that they have no competing interests.
Acknowledgement: The author(s) gratefully acknowledge enormous support given by the Facility Unit staffs of UiTM Sarawak for their assistance throughout this study.

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