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Effect of Organic Loading Rates on Pulp and Paper Wastewater Treatment Using an Anaerobic Upflow Fixed-Film Reactor

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Abstract— **Pulp and paper industry generates large volumes of highly heterogeneous wastewaters containing compounds from wood or other raw material, process chemicals as well as compounds formed during processing. This study has designed a fixed film reactor which uses the concept of biological attached growth treatment to treat the pulp and paper eflfuent. The laboratory-scale fixed film reactor is designed with a circular column of 120 cm height, 15 cm inner diameter and a total volume of 23000 cm^3. The column which constructed in PVC was packed with PVC plastic pipes which were cut into the size of 4.5 cm length and 3 cm diameter and had a specific surface area of 42 cm^2. An amount of 150 PVC plastic pipes were placed in the digester. The system was found could remove about 53% of BOD$_5$ and 89% COD.**

Keywords-pulping effluent; biological treatment; COD; BOD$_5$; Anaerobic

I. INTRODUCTION

Pulp and paper mill industry is a major consumer of water. Thus, it produces a large number of wastewater with high organic loading. The pollutants of effluent from pulp and paper mill could be characterized by biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), toxicity and color when untreated or poorly treated effluent are discharged to receiving water. The effluents from the industry could cause slime growth, thermal impacts, scum formation, color problems and loss of aesthetic beauty in the environment [1]. Conventional treatment currently used is aerobic digestion which requires larger space and much ancillary equipments like aerator and agitator. This will increase the cost of operation and maintenance.

Pulping is the initial stage of the paper making industry. The wood chips are cooked with chemicals such as NaOH at high temperature (180°C) in a pressurized digester. After cooked, the pulp produced is washed with a large number of water and lastly, it will be gone through several processes such as screening, washing, bleaching and paper machine and coating operations. The contains of wastewater are wood debris, soluble wood materials, resins, fatty acids, color, BOD, COD, AOX and VOCs [1,2,3,4]. According to [5], the characteristic of wastewater from pulp and paper mill are BOD$_5$: 1600 – 13,300 mg/l; COD: 5020 – 27,100 mg/l and suspended solid: 16 – 6095 mg/l. This shows that the wastewater from pulp and paper mill is very high strength and suitable for biological treatment because it has high BOD$_5$ value and organic compounds from wood which are food for microorganism.

In the conventional pulp and paper mill waste water treatment plant, water is screened with coarse filters, grit removal, and pH adjustment in the pre-treatment stage. The adjustment of pH is made by metering effluents from various parts of the mill together. The acid line from the chlorination stage raises the pH of other lines that tend to be alkaline. Washed grits from kraft liquor recovery will be ground and used to raise the pH. In the primary treatment, solids are removed by settling them from the water using mechanical clarifier. The clarified wastewater is removed at the outer edge of the tank. Floating debris is collected by a surface skimmer. The sludge is collected and dewatered. It is then disposed to landfill or incinerated or spread on agricultural fields. Air flotation also can be applied for solids removal and this method is more effective but expensive. Secondary treatment involves reaction of the effluent with oxygen and microorganisms (bacteria & fungi) to remove oxygen-consuming materials [6]. The effluent is prepared by pH balancing and addition of nutrients. The BOD is typically reduced by 80-90% during secondary treatment [7]. Tertiary treatments are advanced treatment following secondary treatment. They are often considered for colour removal. The methods that could be applied are ultrafiltration, flocculation and carbon adsorption. Treatment with batch reactors seeded with a mixed culture of algae could reduce 84% of colour [4].

Anaerobic digestion is the most suitable method for the treatment of high strength organic effluents [1,3]. The presence of biodegradable components in the pulp and paper mill effluent makes it suitable to be treated using anaerobic digestion. During anaerobic digestion in wastewater treatment process, biogas will be generated as by-product and this gas could be used as fuel. The microorganism in the anaerobic digestion system will convert the organic molecules into biogas. Fixed firm reactor is an anaerobic digester with biofilm support structure like activated carbon, polyvinyl chloride (PVC) supports, hard rock particles or ceramic rings for biomass immobilization. The wastewater is distributed from below the media. The advantages of using this reactor to treat wastewater from pulp and paper mill are simple to construct, economic, elimination of mechanical mixing, better stability at higher loading rate, able to withstand large toxic shock loads and organic shock loads [3,8,9]. Fixed film reactor could solve the problem of limited space because it utilizes lesser space compare to the activated sludge system which normally be used in conventional waste water treatment. Another advantage of anaerobic digestion is this system is simple and do not require many ancillary equipments like aerator and mixer. Anaerobic treatment which using biofilm reactor could achieve 90% removal of sulphur [10] and 80% removal of COD [2].

The wastewater from the pulp and paper mill should be well treated before discharge to the river to avoid any negative impacts to the environment. Aerobic digestion using activated sludge system is the conventional biological treatment in pulp and paper mill. But this system requires high energy to agitate and provide the oxygen into the wastewater and it also requires large space. Anaerobic system which using fixed film reactor could resolve these problems because it does not require any mixing agitator and aerator and also just need a small space. Besides these, anaerobic digestion could produce biogas as by-product and this gas could be used as fuel to save energy.

Anaerobic treatment is ideally suited for the treatment of high-strength wastewaters that are typical of many industrial facilities including pulp and paper mills. The anaerobic process utilizes naturally-occurring bacteria to break down biodegradable material in the absence of oxygen. The factors such as pH, temperature and nutrient supply are the important requirement for the system to operate properly.

This project is apply a biological treatment for the reduction of BOD, COD, and lead metal in the pulp and paper mill wastewater using anaerobic treatment method. To achieve these objectives, process will be conducted using a Fixed Bed Reactor which based on attached growth system. The principle of operation is that wastewater is passing through a column filled with an inert packing material which acts as a support surface for the growth of large amounts of attached microorganisms.

II. Material and Methods

A. Pulp and Paper Mill Wastewater

The wastewater was obtained from a local pulp and paper mill in the area of Nibong Tebal, Pulau Pinang. This pulp and paper mill is using recycled paper collected from various sources. Table I shows the basic characterization results of the real pulp and paper mill wastewater.

TABLE I. Characteristics Of Papermill Wastewater

Parameter	Concentration (mg/l)
COD	2238 – 3567 (2903)
BOD_5	945 – 1530 (1237)
TSS	950 -3400 (2175)
pH	7.2 – 7.6 (7.4)

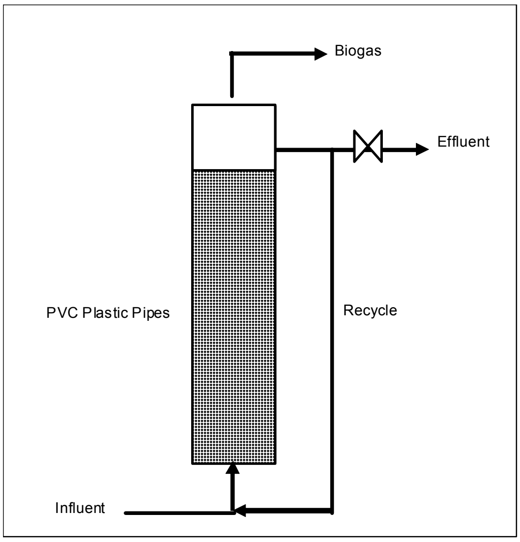

Figure 1. Schematic diagram of an Anaerobic Fixed Film Reactor

B. Fixed Film Reactor Operation

This study was performed on a laboratory-scale fixed film reactor as designed in the schematic diagram shown in Fig. 1. The unit process is an up-flow anaerobic attached growth treatment process. Generally, anaerobic fixed bed digester made of a circular column of 120 cm height, 15 cm inner diameter and a total volume of 23000 cm^3. The column which constructed in PVC was packed with PVC plastic pipes of 4.5 cm length and 3 cm diameter and had a specific surface area of 42 cm^2. An amount of 150 PVC plastic pipes were placed in the digester. The digester is instrumented with the following devices including pump, heater, temperature controller, storage tank, one main supply control valve and wastewater flow meter.

The seed sludge for the system was obtained from the paper mill in Nibong Tebal's wastewater treatment plant. The fixed film reactor was operated at the room temperature which is around 25°C. The feed, which was the real wastewater from paper mill was pumped into the reactor. Initially the reactor was seeded with a mixture of sludge (20% v/v) and substrate and this mixture was recirculated for 2 days. The reactor was then fed continuously with a hydraulic retention time (HRT) 12 h, 24 h and 48h. The reactor operation conditions are given in Table II.

C. Analytical Methods

The BOD_5 and COD were analyzed using the Standard Methods for the Examination of Water and Wastewater of the American Public Health Association (APHA) and is approved by the U.S. Environmental Protection Agency (USEPA); Dilution Method.

TABLE II. REACTOR OPERATION CONDITIONS

Phase	HRT (h)	OLR (kg COD/m^3·d)
I	12	1.21
II	24	0.67
III	48	0.43

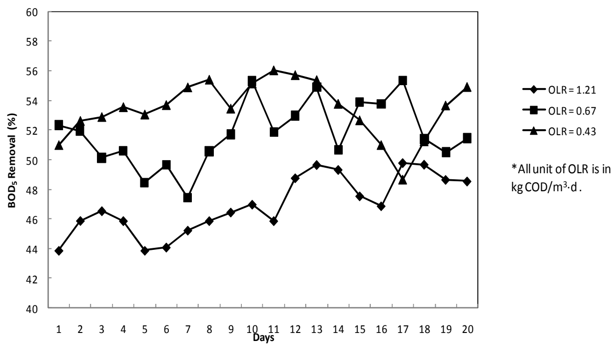

Figure 3. BOD$_5$ Removal

III. RESULTS AND DISCUSSION

A. COD Removal

A decrease of COD removal efficiency occur when the OLR in the fixed film reactor increased as shown in Fig. 2. When the OLR increased from 0.42 to 1.21 kg COD/m^{-3}·d, the COD removal efficiency decreased from averagely 89 % to 84%. The results in this study were consistent with the investigation conducted by [11, 12, 13]. Reference [11] which using fixed film reactor to treat slaughterhouse wastewater, found that when the OLR increased from 8 to 30 kg COD/m^{-3}·d, the COD removal decreased from 85-95% to 55-75%. Reference [12] found that increase in OLR has shown gradual increase in COD removal up to 10 kg COD/m^{-3}·d but after that the COD removal was dropped when using fixed film reactor to treat high suspended solids from a bulk drug industry. Patel, et al. also found the same results when using fixed film reactor to treat the chess whey. It is concluded that the high OLR will inhibite the biomass activity and the designed reactor can operated up to 1.21 kg COD/m^{-3}·d.

The results also showed that at the high OLR which is at 1.21 kg COD m-3 day-1, the COD removal efficiency range is large compare to lower OLR. The COD removal efficiency was range from 75% to 84% at highest OLR while only range from 87% to 92% at lowest OLR. This shows that the COD removal efficiency is more reliable operated at lower OLR. At the highest OLR, the COD removal could maintain above 85% from day 10 to 16 but it decreased after the day 14 until the last day operation. It evidence that the biomass activities were obstructed after the day 14.

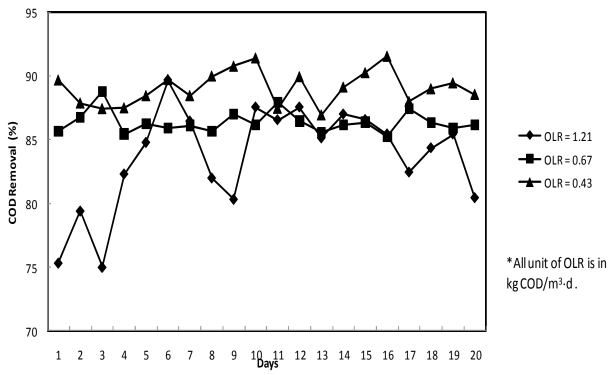

Figure 2. COD Removal

B. BOD$_5$ Removal

The BOD$_5$ removal efficiency trend is similar to the COD removal efficiency. The Fig. 3 shows that the BOD$_5$ removal efficiency is highest on the lowest OLR. Averagely, at OLR 0.43 kg COD/m^{-3}·d, the BOD$_5$ removal efficiency could achieve 53.4% while at OLR 1.21 kg COD/m^{-3}·d; the BOD$_5$ removal efficiency could achieve 43.9% only. These results also consistent with the findings of [14] where they studied the performance of anaerobic upflow fixed-film reactor on the acidic petrochemical wastewater and they found that the BOD$_5$ of reactor effluent was increasing when the OLR was increased.

The BOD$_5$ removal in this study was low compare to [12]. The highest removal could be achieved is only 53.4% but according to [12], the removal was around 90%.

IV. CONCLUSIONS

This study reveals the potentiality of using upflow fixed film reactor for wastewater from pulping and paper industry with high strength loading. The reactor could achieve 89% COD removal efficiency and 53% BOD$_5$ removal efficiency at OLR 0.42 kg COD/m^{-3}·d. The designed system has to be improved in removing the BOD5 and the biogas production from the system has to be investigated in future.

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