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Anaerobic Biological Treatment of Wastewater from Paper Recycling Industry by UASB Reactor

(Rawatan Biologi Anaerobik Air Sisa daripada Industri Kitar Semula Kertas oleh Reaktor UASB)

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ABSTRACT

The use of an upflow anaerobic sludge blanket (UASB) reactor for the treatment of paper recycling industry effluent containing different pollutants was investigated. In the first phase, reactor was fed with anaerobic sludge and in the second phase, synthetic influent solution with different macro-nutrients and micro-nutrients, trace elements as well as glucose were added as a basis of food and energy. In order to enhance sludge granulation and increase the growth, anaerobic bacterial biomass culture was added and operated for one month. Samples from paper recycling industry effluent with different dilutions were analyzed at a hydraulic retention time (HRT) of 24 h and at 37 °C mesophilic temperature. The removal efficiencies of chemical oxygen demand (COD), biological oxygen demand (BOD), electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), nitrates, phosphates, heavy metals (Hg, Pb, Cd, Cr, Cu) and pH were upto 87%, 93%, 77%, 79%, 88%, 82%, 92%, 94%, 86%, 91%, 93%, 98%, 98%, and 7.21 with different of wastewater concentration/percent dilutions 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1, 10:0 wastewater. This study concluded that UASB technique was a suitable choice for treating different pollutants in paper recycling industry wastewater.

Keywords: Paper recycling industry wastewater; substrate utilization rate; upflow anaerobic sludge blanket (UASB) reactor; wastewater treatment

ABSTRAK

Penggunaan reaktor enapcemar anaerobik aliran atas (UASB) untuk rawatan efluen industri kitar semula kertas yang mengandungi bahan pencemar berbeza telah dikaji. Pada fasa pertama, reaktor telah disuap dengan enapcemar anaerobik dan pada fasa kedua, larutan influen sintetik dengan nutrien makro dan mikro-nutrien yang berbeza, unsur surih serta glukosa ditambah sebagai asas makanan dan tenaga. Untuk meningkatkan granulasi enap cemar dan meningkatkan pertumbuhan, kultur biojisim bakteria anaerobik telah ditambah dan dikendalikan selama satu bulan. Sampel daripada efluen industri kitar semula kertas dengan pencairan berbeza dianalisis pada masa pengekalan hidraulik (HRT) selama 24 jam dan pada suhu mesofilik 37 °C. Kecekapan penyingkiran permintaan oksigen kimia (COD), permintaan oksigen biologi (BOD), kekonduksian elektrik (EC), jumlah pepejal terlarut (TDS), jumlah pepejal terampai (TSS), jumlah pepejal (TS), nitrat, fosfat, logam berat (Hg, Pb, Cd, Cr, Cu) dan pH adalah sehingga 87%, 93%, 77%, 79%, 88%, 82%, 92%, 94%, 86%, 91%, 93%, 98%, 98% dan 7.21 dengan kepekatan air sisa/peratus pencairan 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1, 10:0 air sisa. Kajian ini merumuskan bahawa teknik UASB adalah pilihan yang sesuai untuk merawat bahan pencemar yang berbeza dalam air sisa industri kitar semula kertas.

Kata kunci: Air sisa industri kitar semula kertas; kadar penggunaan substrat; rawatan air sisa; reaktor enapcemar anaerobik aliran atas (UASB)

INTRODUCTION

Industrialization has played a significant role in polluting the environment due to excessive release of toxic compounds in the environment. Once the industrial effluents are released in the environment, they become a part of air, soil, surface and ground water depending upon the state of pollutant released (Iftikhar et al. 2020; Patel et al. 2017). Over the past several decades, the paper recycling industry has expanded significantly. After chemicals and metals industries, paper recycling industry produce the third largest quantity of wastewater (Ashrafi, Yerushalmi & Haghighat 2015).

Lots of water is consumed in the process of paper recycling (75 to 227 m^3 of water is used to process one ton of the product), which ultimately leads to the generation of a huge quantity of wastewater (Bakraoui et al. 2020; Ginni et al. 2014; Gupta et al. 2022). Different inorganic and organic pollutants that mostly arise from resins, lignin, suspended solids, nitrates, chlorine compounds, heavy metals phosphates, ammonia, tannins, and volatile fatty acid are present in wastewater (Buzzini & Pires 2007; Zwain, Aziz & Dahlan 2016). The wastewater has adverse impacts on the environment and causes a severe danger to human, flora and fauna.

The wastewater from paper recycling industry contains large quantities of organic matters which can be treated by various treatment methods namely coagulation and precipitation, reverse osmosis, sedimentation and flotation, filtration, adsorption, ozonation, advanced oxidation processes, wet oxidation, biological treatment methods, such as aerobic treatment, anaerobic digestion, and fungal treatment (Cai, Lei & Li 2019; Kamali & Khodaparast 2015). Anaerobic digestion is one of the foremost suitable and effective method that has been utilized to treat municipal and industrial wastewater. It can stabilize the organics present in wastewater and produce methane which is a renewable energy source (Chatterjee & Mazumder 2019). A variety of microorganisms and enzymes are responsible of this process involving hydrolysis, acidogenesis, and methanogenesis accomplishing the decomposition of organic matter in an oxygen-deficient environment (Tawfik et al. 2022). The anaerobic biological treatment is advantageous over the physicochemical and aerobic treatment of industrial effluents (Ashrafi, Yerushalmi & Haghighat 2013; Zwain et al. 2013).

Owing to low sludge production, and technical simplicity, numerous developing nations are preferring anaerobic processes over aerobic treatment for their wastewater (Bhatti et al. 2014). Up-flow anaerobic sludge blanket (UASB) reactor operates by vertically flowing liquid substrate, such as wastewater or growth media, through a blanket of anaerobic sludge (Pererva, Miller & Sims 2020). Inside the sludge, the layer of microbial consortia consumes edible components as substrates and stabilize these chemical compounds. In wastewater treatment, the objective of anaerobic digestion is to stabilize the organic compounds in addition to the generation of biogas as a source of energy (Fang, Chui & Li 1994). A bed of granular sludge at the bottom of the UASB reactor is an effective concept since it can generate energy in the form of methane while eliminating COD with reasonably high efficiency (Van Lier et al. 2015). The development of granular sludge in UASB reactors with strong methanogenic activity was one of the fundamental criteria to judge process performance of the anaerobic digestion (Rosa et al. 2018).

The aim of this study was to evaluate the treatment efficiency of UASB reactor for paper recycling industry wastewater under mesophilic conditions. The performance was evaluated in terms of COD removal and removal percentage of many other wastewater quality parameters.

MATERIALS AND METHODS

CHARACTERISTICS OF EFFLUENT FROM PAPER RECYCLING INDUSTRY

Samples of wastewater were taken from the Zaman paper recycling industry located at Hattar Industrial Estate Haripur City, Pakistan. The characteristics of paper recycling industry are presented in Table 1. The wastewater was characterized for its various physicochemical parameters according to American Public Health Association guidelines (APHA 2007). The results show that paper recycling industry wastewater comprises inorganic and organic matters required for biological development. The influent contained a high BOD_5/COD proportion of 0.41, indicating that it contains a lot of biodegradable organic matter and might be suitable for anaerobic treatment. The BOD_5/COD ratio of 0.5 demonstrates the high strength organic nature of this effluent (Zwain et al. 2013). Table 2 shows the strength of wastewater fed to the UASB reactor during this study. Quality assurance and quality control (QA/QC) was exercised in careful handling of the sampling process and their analyses. Wastewater samples were collected as grab composite samples in cleaned plastic containers, and transported to the laboratory at COMSATS University as soon as possible. Before the experimental treatment, the wastewater was characterized following the guidelines provided by APHA, USA. Each sample was analyzed in triplicates for precision and accuracy. The instruments were calibrated by running standards and operating manuals. The data were reported as means of three independent readings.

TABLE 1. Influent characterization of paper recycling industry wastewater

Sr. No.	Parameters	Unit	Paper recycling industry wastewater/ StDev
1.	pH	-	7.93±0.0577
2.	EC	**µs**/cm	4493.66±0.577
3.	COD	mg L^{-1}	1020.33±2.081
4.	TDS	mg L^{-1}	560.66±1.527
5.	TSS	mg L^{-1}	311±1.732
6.	TS	mg L^{-1}	871.66±1.154
7.	BOD	mg L^{-1}	427.33±1.527
8.	Nitrate	mg L^{-1}	72.33±3.511
9.	Phosphate	mg L^{-1}	127.33±0.577
10.	Hg	mg L^{-1}	11.13±0.005
11.	Pb	mg L^{-1}	3.64±0.003
12.	Cd	mg L^{-1}	6.01±0.005
13.	Cr	mg L^{-1}	11.44±0.002
14.	Cu	mg L^{-1}	11.76±0.002

PILOT-SCALE MESOPHILIC UP-FLOW ANAEROBIC SLUDGE BLANKET REACTOR (UASB)

Figure 1 shows a schematic diagram of UASB reactor fed with paper recycling industry wastewater and operated under mesophilic conditions. The UASB reactor had a cylindrical shape with a working volume of 2 L made of transparent perspex material.

EXPERIMENTAL SETUP AND PROCEDURE

Anaerobic degradation of paper recycling industry wastewater was studied by using a UASB reactor to evaluate the pollutant degradation potential of anaerobic mixed microbial consortium. The reactor was operated in continuous mode and at a HRT of 24 h in the beginning with the lowest organic loading rate from 90% dilution; later it was gradually increased to 100% original wastewater based on the removal efficiency of the reactor. Various operational conditions the reactor were shown in Table 3.

Initially, the reactor was inoculated with active anaerobic sludge from anaerobic treatment system. Afterwards synthetic influent solution was fed into the reactor continuously for 21 days as indicated in Table 2. In order to support the microbial growth, synthetic nutrient solution containing different macro-nutrients and micro-nutrients, trace elements were also fed in order to achieve sludge granulation by increasing growth of anaerobic bacterial biomass (Mahmood et al. 2007).

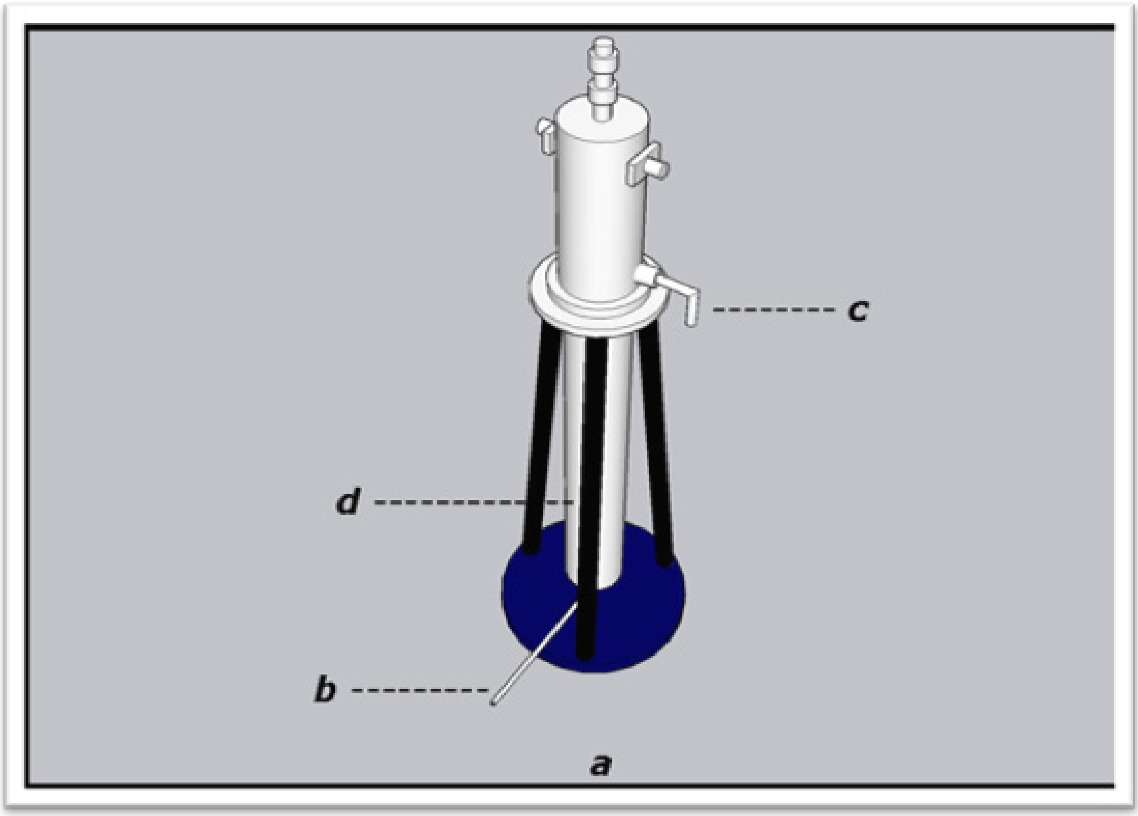

FIGURE 1. (a) Schematic diagram of Up-flow Anaerobic Sludge Blanket Reactor (UASB) for treatment of paper recycling industry wastewater (b) Influent of the reactor (c) Effluent of the reactor (d) Sludge and wastewater

TABLE 2. Dilutions for wastewater in UASB reactor

Sr. No	Code	Wastewater (mL)	Distilled water (mL)
1.	1:9 WW	100	900
2.	2:8 WW	200	800
3.	3:7 WW	300	700
4.	4:6 WW	400	600
5.	5:5 WW	500	500
6.	6:4 WW	600	400
7.	7:3 WW	700	300
8.	8:2 WW	800	200
9.	9:1 WW	900	100
10.	10:0 WW	1000	0

TABLE 3. Reactor operating parameters

Sr. No.	Reactor operating parameters	Specifications
1.	Hydraulic Retention Time (HRT) HRT=V/Q	24 h
2.	COD (mg/L)	1020.33±2.081
3.	Temperature (°C)	30-35
4.	Flow rate (L/min)	0.5
5.	Volume of Reactor (Liters)	2 L

Synthetic influent solution (2 g glucose per litre with 1 mL each synthetic solution) was fed into the reactor operating at continuous modes with a flow rate of 0.5 rpm until COD was reduced significantly. Synthetic influent solution was characterized for parameters such as COD, EC, TDS, pH, TSS, TDS, TS, nitrate, and phosphate. Maximum effluent COD was achieved 150 mg/L after 18 days. When reactor reached maximum COD elimination effectiveness with synthetic wastewater at that point it was moved to industrial wastewater. To check the effectiveness of this reactor for BOD, COD, TDS, TSS, TS, nitrate, phosphate, pH, electrical conductivity, heavy metals (Hg, Pb, Cd, Cr, and Cu) and organic pollutants were analyzed before and after treatment. All parameters were analyzed by standard methods.

CHEMICAL ANALYSIS

The parameters that were analyzed at laboratory scale were COD, BOD, TDS, TSS, TS, nitrate, phosphate, pH, electrical conductivity and heavy metals (Hg, Pb, Cd, Cr, and Cu). All analyses were carried out according to 'Standard Methods for the Examination of Water and Wastewater' (APHA 2007). The COD of the samples were measured through closed reflux colorimetric method using COD digester (HACH - LTG 082.99.40001). In COD, vial sample 2.5 mL were digested in digester with 1.5 mL of the digestion solution and 3.5 mL of sulfuric acid reagents. The COD digestion took place for 2 h at 150 °C and later COD reading was measured by COD spectrophotometer. The pH of the samples was checked by means of digital pH Meter (Jenway model 520). Electrical conductivity of the wastewater samples was analyzed by using conductivity meter. The concentration of phosphates was analyzed by using UV-VIS Spectrophotometer (IRMeCO UV-Vis, U2020). Water sample about 20 mL was taken in beaker, then stannous chloride (0.4 mL) was added. Then, 1 mL of aluminum molybdate was added. The sample was examined by spectrophotometer at 680 nm when blue color was developed (APHA 2007). The nitrates concentration was analyzed by UV-VIS Spectrophotometer (IRMeCO UV-Vis, U2020). Sample (20 mL) was taken and 1 mL of 0.1 N HCl was added. The solution was properly mixed. The absorbance of the sample was determined at 220 nm. The absorbance of the sample obtained at 220 nm was changed to concentration, using calibration curve (APHA 2007). Heavy metals concentration was analyzed using Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst 700) at definite wavelength. Wastewater sample were filtered and analyzed by Atomic Absorption Spectrophotometer (APHA 2007). Total suspended solids were calculated by the filtration method. A pre-weighed filter paper was employed to filter a well shaken sample. After that the filter paper was dried in the drying oven at 105 °C. Once completely dried, the filter paper was weighed again and TSS was calculated as:

$$\textit{Total Suspended Solids} = W2 - W1$$

where W2 is the final weight of the filter paper, and W1 is its initial weight (APHA 2007). In order to calculate the total dissolved solids, 50 mL of the filtered sample was allowed to evaporate in a pre-weighed China dish using a heating plate. Once the sample has completely evaporated, the China dish was weighed again. Total dissolved solids were calculated using the following formula:

$$\textit{Total Dissolved Solids} = W2 - W1$$

where W1 is the initial weight of the china dish; and W2 is the final weight of the China dish (APHA 2007). Total solids were calculated as the sum of TDS and TSS with the following equation (APHA 2007)

Total Solids = Total Dissolved Solids + Total Suspended Solids

RESULTS AND DISCUSSION

The study focused on the anaerobic treatment of paper recycling industry wastewater in UASB reactor in continuous mode feeding different dilutions of wastewater (1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1, and 10:0). Following are the results of various wastewater quality parameters.

EFFECT OF CHEMICAL OXYGEN DEMAND (COD) & BIOLOGICAL OXYGEN DEMAND (BOD)

The data presented in Figure 2 showed the COD and BOD removal in UASB reactor. It was evident that COD of the 1:9 diluted wastewater decreased. With the decreasing ratios of wastewater, the COD loading of the influent increased and so the highest COD of influent 1020.33 mg/L was observed at 10:0 (pure) wastewater. The results showed the COD removal efficiency decreased as COD loading was increased. The COD removal percentages were in the range of 40 to 87% for various dilutions of wastewaters used at 24 hours HRT. Wastewater that comes out from the recycled paper mill wastewater usually possesses high degradability. The average COD removal efficiency was up to 87.17% for dilutions and for the original wastewater it was 28.68% (Meyer & Edwards 2014) in their research determine the anaerobic treatability of paper recycling industry wastewater. It was reported that the anaerobic treatment was suitable choice for paper wastewater which reduced the COD (58-86%). Gotmare, Dhoble and Pittule (2011) reported 75-85% COD removal. In another study by Bakraoui et al. (2020), a UASB reactor was employed to study its efficiency in treating the recycled paper mill wastewater which reported the COD removal efficiency of 80.63%. One of the reasons of large variations of COD removal in the present work could be the temperature and the HRT of the system. The treatment was done during the winter season at room temperature of 28-29 °C. No additional heating was provided as the reactor was said to generate its own during treatment. The anaerobic bacteria are characterized by their slow growth and slow substrate utilization rate. Meyer and Edwards (2014) explained the low COD removal efficiency in the continuous mode at lower HRT.

BOD removal also displayed similar trends during the treatment. Figure 2 showed that with decreasing the dilution of wastewater, concentration of influent increased and so the highest BOD of influent 427.33 mg/L was observed at the 10:0 wastewater. The obtained results showed a reduction in BOD effluent where the BOD removal efficiency reached 93.37% for 1:9 dilution, while it was 45.86% for 10:0 wastewater at 24 hours HRT. Gotmare, Dhoble and Pittule (2011) in their research, reported 88-94% BOD removal.

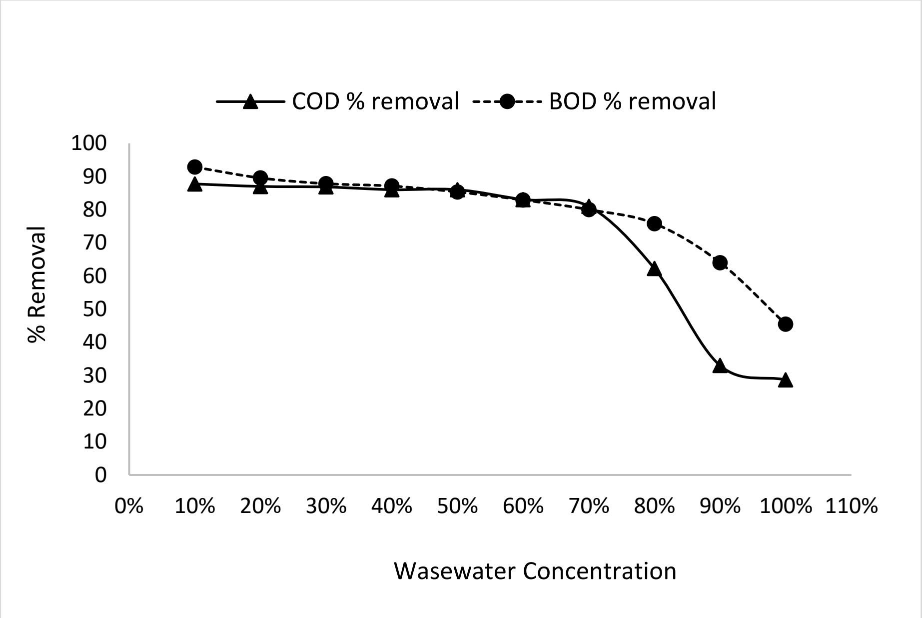

FIGURE 2. Effect of Chemical Oxygen Demand (COD) & Biological Oxygen Demand (BOD)

EFFECT OF pH

Figure 3 showed the pH variations in UASB during treatment. The influent pH range was 7.7 to 7.90. Meanwhile, for the pH range for the effluent was 7.31 to 7.8. It showed that there was slight variation in the system pH during the treatment. The pH of the system after anaerobic treatment fluctuated from 7.71 - 7.66. At the time of anaerobic treatment of paper recycling industry wastewater (Zwain et al. 2013) recorded alteration in the system pH (7.3 to 6.2). From the alteration, they deduced that the fluctuations can be caused due to the micro-organisms adjusting to their environment. When it comes to pH of the system, it is a censorious aspect as it effects the metabolic activities of the micro-organisms as well as their growth. Among the hydrolytic micro-organisms, most of bacteria work at the pH between 5 and 7, while for the methanogens have the optimum pH between 6.5 and 8.5. Any alterations above or below the critical pH levels greatly affect hydrolytic and methanogenic bacteria, especially the latter one since they are more susceptible to pH fluctuations (Kim et al. 2003). In this study, the pH underwent fluctuations but they were below the critical levels hence no major disturbances were caused during experiment.

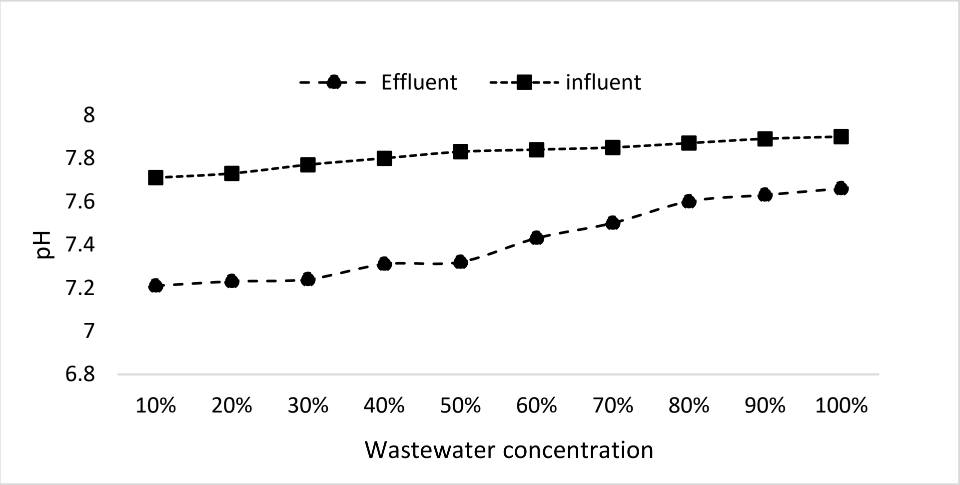

FIGURE 3. Effect of pH

EFFECT OF ELECTRICAL CONDUCTIVITY

Figure 4 shows the trend in electrical conductivity (EC) during anaerobic treatment. With increasing each loading of wastewater, the EC of the influent increased. The lowest influent EC was observed at loading at 1:9 dilution (331.33 µS/cm, 77.04%), while the highest EC of 493.66 µS/cm (32.11%) was observed at 10:0 wastewater. The percentage average change in EC during treatment was observed to be 77.04%.

EFFECT OF TOTAL DISSOLVED SOLIDS (TDS), TOTAL SUSPENDED SOLIDS (TSS), TOTAL SOLIDS (TS)

Figure 5 demonstrated the pattern of TDS, TSS, and TS removal. The influent TDS was 566.66 mg/L and the effluent TDS concentration reported was 311.33 mg/L. The influent TDS increased gradually from dilution 1:9 till 10:0 wastewater. After anaerobic treatment, the effluent TDS decreased. The highest decrease in TDS was observed for 1:9 dilution (79.04% decrease). While the least decrease in TDS was found when the influent had 10:0 wastewater 44.47%. Similarly, the influent TSS gradually increased from dilution 1:9 till 10:0 wastewater. After anaerobic treatment, the effluent TSS decreased. The highest decrease in TSS was observed for 1:9 dilution, 88.31%. While the least decrease in TSS was found when the influent had 10:0 wastewater which was 54.22%. A study performed by Zwain et al. (2013) on the operation of modified anaerobic baffled reactors at its study state (30 days) showed 50.01% removal of TDS which is higher than obtained in this study. This difference in percentage between the two treatments can be explained in terms of sludge to wastewater contact. Continuous treatment having higher contact between sludge and wastewater depicted high TDS removal. But the HRT during the continuous treatment was 24 h hence the TDS removal could have been higher if the HRT was raised to 48 h or more.

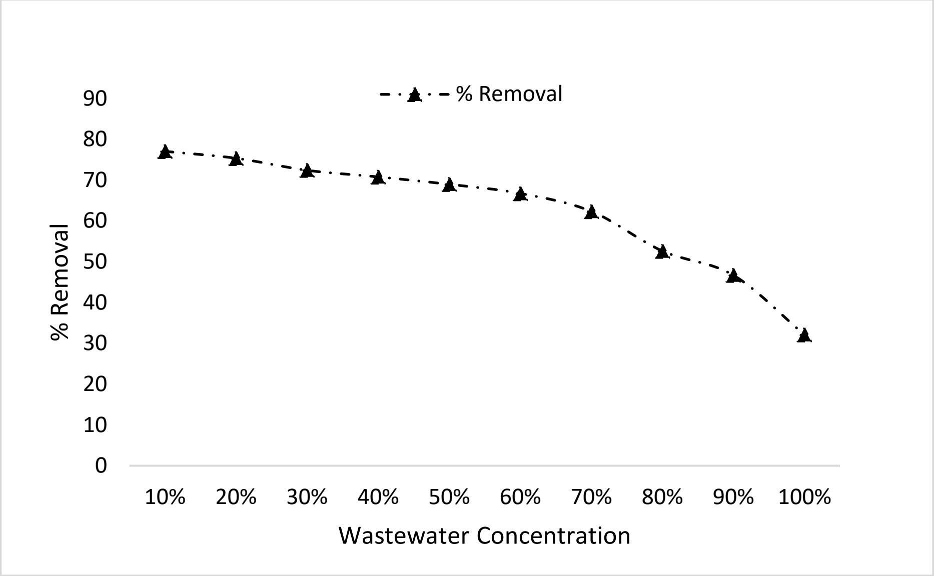

FIGURE 4. EC variations during paper recycling wastewater treatment in UASB

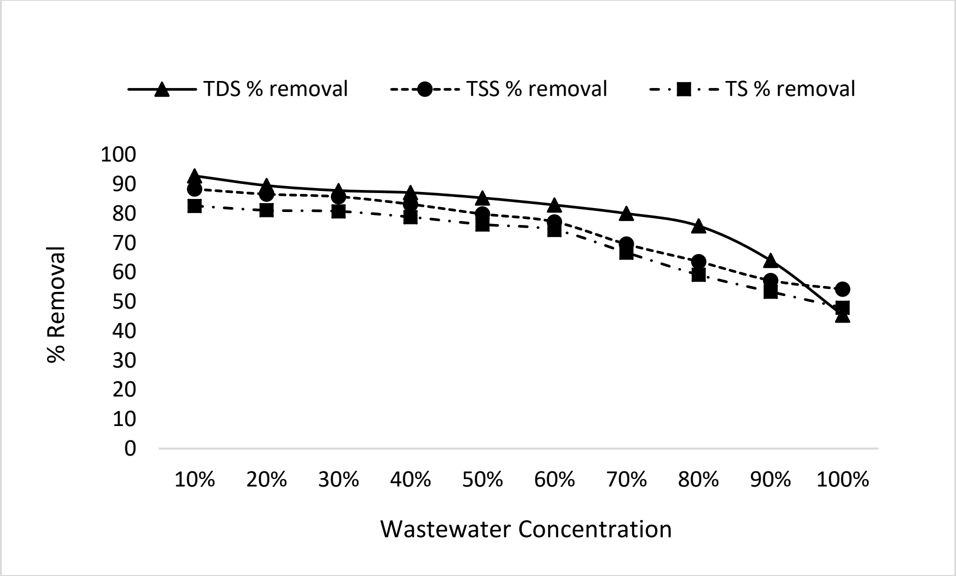

FIGURE 5. Effect of Total Dissolved Solids Total Suspended solids (TSS) and Total Solids (TS)

NITRATE & PHOSPHATE REMOVAL

Data presented in Figure 6 showed the nitrate concentration during treatment. The highest nitrate removal efficiency was noted during the experiment with 1:9 dilution. The influent nitrate concentration at 1:9 was 72.33 mg/L and the effluent concentration was 5.66 mg/L with nitrate removal efficiency of 92.13%. The lowest removal of nitrate was observed at 10:1 and the nitrate concentration of influent was 66.00 mg/L and the effluent nitrate concentration lowered to only 41.66 mg/L with 42.23% removal. The removal efficiencies during treatment were in the range of 42.23% to 92.13% for all wastewater samples. The average removal of nitrate during treatment was 42.23%. Krishna, Sarkar and Mohan (2014) had reported a nitrate removal efficiency of 19.00% during anaerobic treatment of paper industry wastewater. During anaerobic conditions, the nitrates acts as electron acceptors for anaerobic respiration and thus gets reduced to nitrogen gas. Ma et al. (2013) conducted experiments on anammox removal of nitrogen in UASB reactor and reported that nitrogen uptake rate decreased with decrease in temperature. They observed that the progressive decrease of temperature from 30 °C to 16 °C caused a decrease in nitrogen removal rate (NRR). Thus, the decrease in nitrate removal efficiency in continuous treatment can possibly be due to the difference in the temperature during the treatment.

Figure 7 showed pattern of change in influent and effluent phosphate concentration and its removal efficiency during treatment. The maximum removal efficiency of phosphate was reported at 1:9 dilution during which the influent phosphate concentration was 46.66 mg/L and effluent had a phosphate concentration of 6.66 mg/L and a removal efficiency of 94.76%. The lowest removal efficiency of nitrate was discerned at 1:0 wastewater. The phosphate concentration of influent was 127.00 mg/L of phosphate had a removal efficiency of 41.20%. The average removal of phosphates during treatment was 41.20%. Krishna, Sarkar and Mohan (2014) have reported only 17% removal. Yeoman et al. (1988) found out about the behavior of phosphorus during wastewater treatment that under the anaerobic conditions the phosphate that is often penetrated deep into the sludge is released into the water and so gets effectively removed. The high phosphate removal can also be described in terms of the influent concentrations of phosphate and since phosphate is also used as a macro-nutrient for microbial growth, it caused a higher reduction in the overall phosphate concentration. The reason behind continuous treatment mode having higher phosphate removal efficiency might be an association between the wastewater and the microbial growth in UASB.

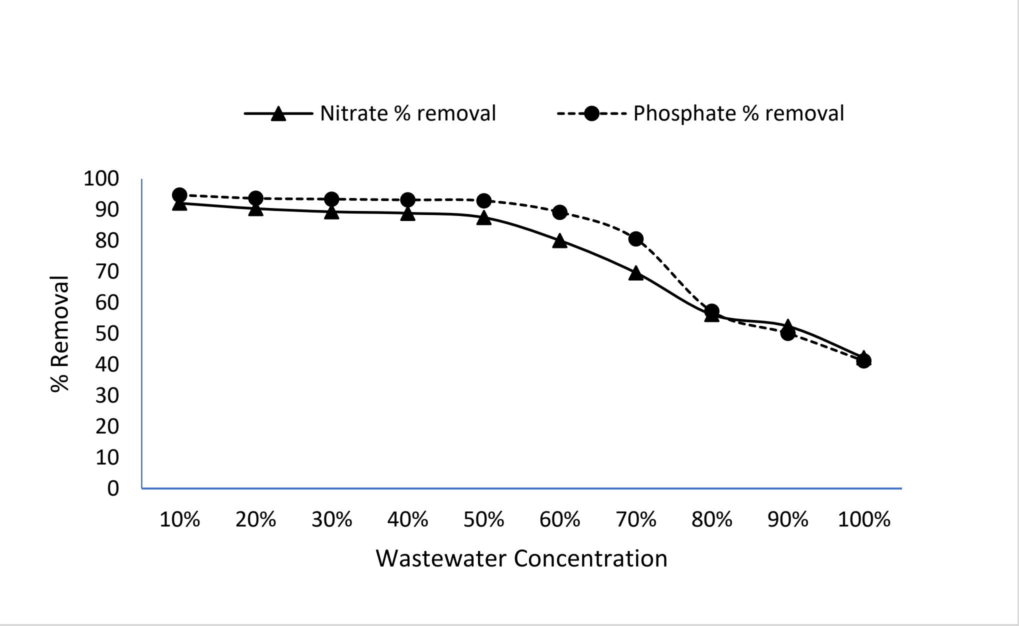

FIGURE 6. Nitrate and phosphate removal in UASB

EFFECT OF HEAVY METALS (Hg, Pb, Cd, Cr, Cu)

Figure 7 shows the concentration of heavy metals (Hg, Pb, Cd, Cr, Cu) concentration during treatment. The highest Hg removal efficiency was noted during the experiment with 1:9 dilution. The influent nitrate concentration at this point was 3.69 mg/L and the effluent concentration came out to be 1.62 mg/L with Hg removal efficiency of 85.41%. The lowest removal of Hg was observed at 10:1 wastewater when the influent concentration was 11.13 mg/L and Hg effluent concentration lowered to only 7.15 mg/L with 35.73% removal.

With the decreased dilution of the wastewater, the influent concentration increased and so the highest Pb influent concentration of was observed at 10:0 wastewater which was 1.44 mg/L. The achieved results exhibit a decline in lead concentration effluent, and the percent removal efficiency was 91.48% removal for 1:9 dilution, 90.93% for 2:8 dilution, 88.18% for 3:7 dilution, 86.08% for 4:6 dilution, 82.41% for 5:5 dilution, 79.94% for 6:4 dilution, 76.55% for 7:3 dilution, 68.58% for 8:2 dilution, 62.82% for 9:1 dilution, and 60.43% for 10:0 wastewater at 24 hours HRT.

Trend of Cd during anaerobic treatment was also shown in Figure 8. With increasing the concentration of wastewater, the concentration of Cd also increased. The lowest influent Cd was observed at loading at 1:9 dilution which is 0.58 mg/L, while the highest Cd of 3.74 mg/L was observed at 10:0 wastewater. After treatment the Cd concentration reduced from the graph it can be seen, 90.24% Cd was reduced at 1:9 dilution which was the highest reduction in the treatment.

In Figure 8, it is showed how Cr varied during the treatment. The influent Cr was 11.44 mg/L. The influent Cr increased gradually from dilution 1:9 till 10:0 wastewater. The highest decrease in Cr was observed for 1:9 dilution, 98.51%. While the least decrease in Cr removal was found when the influent had the 10:0 wastewater 21.75%.

With increasing each loading of wastewater, the concentration of Cu also increased. The lowest influent Cu was observed at loading at 1:9 dilution which is 0.23 mg/L, while the highest Cd of 9.24 mg/L was observed at 10:0 wastewater. After treatment, 98.44% Cu concentration reduced, at 1:9 dilution which is the highest reduction in the treatment. The lowest reduction in Cu was 21.37%, observed at 10:0 wastewater.

Adsorption and complexation are the two processes through which heavy metals are removed in biological processes by microorganisms. More so, there are processes which lead to precipitation and formation of heavy metals. Due to the links between heavy metal ions and negatively charged surfaces of microbes, metals get adsorbed on cell surfaces of microbes (Metcalf, Eddy & Tchobanoglous 1991). A good concentration of soluble heavy metal removal has been recorded in biological processes with percentage removal of 50-98 based on the initial concentration of heavy metals and HRT (Mullen et al. 1989). De la Varga et al. (2013) reported that the hybrid system UASB-CW achieved high heavy metal removal efficiencies for Hg (42%). The lowest reduction in Cd was observed at original wastewater with no dilution which is 37.80%. Zeng et al. (2019) reported that the average Cd (II) removal efficiency was 93.6 (± 2.7).

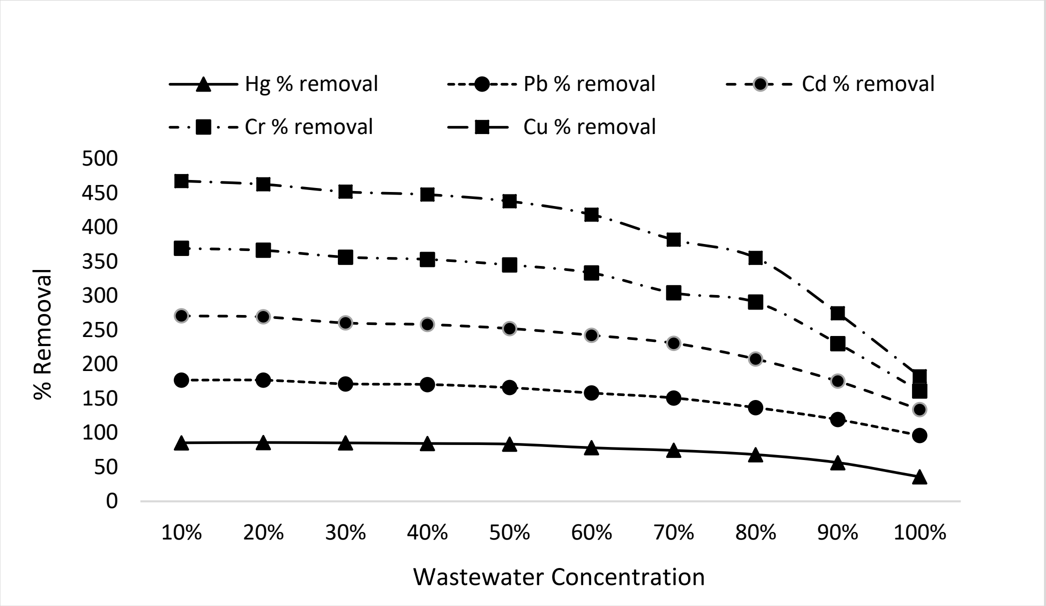

FIGURE 7. Effect of heavy metals (Hg, Pb, Cd, Cr, Cu) removal by UASB

RATE OF UTILIZATION OF SOLUBLE SUBSTRATES

The goal of the biological wastewater treatment is to degrade organic compounds or the removal of substrate. The substrate utilization rate in biological system can be modeled with the following expression for soluble substrates.

$$R_{su} = \frac{KXS}{K_s + S}$$

where r_{su} is the rate of substrate concentration change due to utilization g/m^3.d; k is the maximum specific substrate utilization rate, g substrate/g microbes.d; X is the biomass (microorganisms) concentration/m^3, S is the growth limiting substrate concentration in solution g/m^3, K_S is the half velocity constant, substrate concentration at one half the maximum specific substrate utilization rate g/m^3.

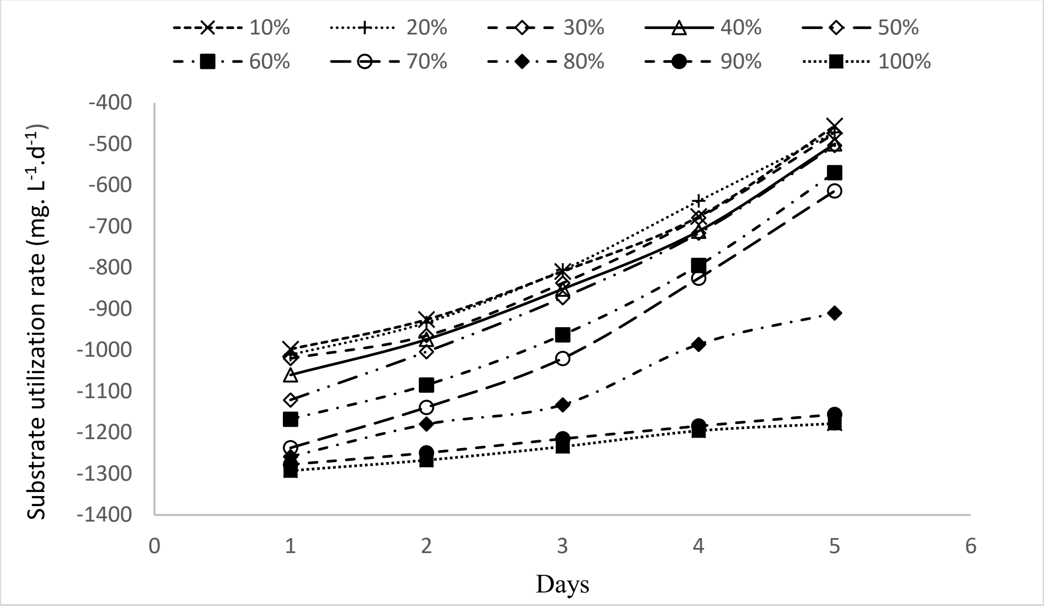

FIGURE 8. Substrate utilization rate

A plot of r_{su} as a substrate utilization rate versus days with different concentration of wastewater shows maximum substrate utilization rate occur at low substrate concentration. The maximum substrate utilization occurs at least concentration which is 10% wastewater and minimum substrate utilization at 100% wastewater. As reported in Metcalf, Eddy and Tchobanoglous (1991), the maximum substrate utilization rate occurs at high substrate concentrations. However, the substrate concentration decreases below some critical value because the COD of wastewater is 1022 mg/L which is very high so there is possibility of microbes dying in the system. Or there are less microbes in the system as compared to substrate.

CONCLUSION

The present work illustrated that influent from paper recycling industry contained very high amount of organic pollutants, outlined by COD values up to 1020 mg/L, which was appropriate to be treated in UASB. The results showed a high influence of wastewater loading on the UASB reactor. It showed good efficiency at 1:9, 2:8, 3:7, 4:6, 5:5 dilution but when the wastewater concentration increases from 5:5, a gradual increase was observed in effluent COD. The other wastewater quality parameters were successfully reduced after treatment in UASB. The findings suggested that some additional methods should be employed to effectively treat COD from the paper recycling industry.

REFERENCES

Apha, A. 2007. *WEF (2005) Standard Methods for the Examination of Water and Wastewater.* Washington: National Government Publication. https://www. worldcat. org

Ashrafi, O., Yerushalmi, L. & Haghighat, F. 2015. Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission. *Journal of Environmental Management* 158: 146-157.

Ashrafi, O., Yerushalmi, L. & Haghighat, F. 2013. Greenhouse gas emission by wastewater treatment plants of the pulp and paper industry - Modeling and simulation. *International Journal of Greenhouse Gas Control* 17: 462-472.

Bakraoui, M., El Gnaoui, Y., Lahboubi, N., Karouach, F. & El Bari, H. 2020. Kinetic study and experimental productions of methane production from UASB reactor treating wastewater from recycled pulp and paper for the continuous test. *Biomass and Bioenergy* 139: 105604.

Bhatti, Z., Maqbool, F., Malik, A. & Mehmood, Q. 2014. UASB reactor startup for the treatment of municipal wastewater followed by advanced oxidation process. *Brazilian Journal of Chemical Engineering* 31: 715-726.

Buzzini, A.P. & Pires, E.C. 2007. Evaluation of a upflow anaerobic sludge blanket reactor with partial recirculation of effluent used to treat wastewaters from pulp and paper plants. *Bioresource Technology* 98: 1838-1848.

Cai, F., Lei, L. & Li, Y. 2019. Different bioreactors for treating secondary effluent from recycled paper mill. *Science of The Total Environment* 667: 49-56.

Chatterjee, B. & Mazumder, D. 2019. Role of stage-separation in the ubiquitous development of anaerobic digestion of organic fraction of municipal solid waste: A critical review. *Renewable and Sustainable Energy Reviews* 104: 439-469.

De la Varga, D., Díaz, M., Ruiz, I. & Soto, M. 2013. Heavy metal removal in an UASB-CW system treating municipal wastewater. *Chemosphere* 93: 1317-1323.

Fang, H., Chui, H. & Li, Y. 1994. Microbial structure and activity of UASB granules treating different wastewaters. *Water Science & Technology* 30: 87-96.

Ginni, G., Adishkumar, S., Rajesh Banu, J. & Yogalakshmi, N. 2014. Treatment of pulp and paper mill wastewater by solar photo-Fenton process. *Desalination and Water Treatment* 52: 2457-2464.

Gotmare, M., Dhoble, R. & Pittule, A. 2011. Biomethanation of dairy waste water through UASB at mesophilic temperature range. *Int. J. Adv. Eng. Sci. Technol*. 8: 1-9.

Gupta, S.K., Singh, B., Mungray, A.K., Bharti, R., Nema, A.K., Pant, K. & Mulla, S.I. 2022. Bioelectrochemical technologies for removal of xenobiotics from wastewater. *Sustainable Energy Technologies and Assessments* 49: 101652.

Iftikhar, A., Khan, M.S., Rashid, U., Mahmood, Q., Zafar, H., Bilal, M. & Riaz, N. 2020. Influence of metallic species for efficient photocatalytic water disinfection: Bactericidal mechanism of *in vitro* results using docking simulation. *Environmental Science and Pollution Research* 27: 39819-39831.

Kamali, M. & Khodaparast, Z. 2015. Review on recent developments on pulp and paper mill wastewater treatment. *Ecotoxicology and Environmental Safety* 114: 326-342.

Kim, Y., Han, K. & Lee, W. 2003. Removal of organics and calcium hardness in liner paper wastewater using UASB and CO_2 stripping system. *Process Biochemistry* 38: 925-931.

Krishna, K.V., Sarkar, O. & Mohan, S.V. 2014. Bioelectrochemical treatment of paper and pulp wastewater in comparison with anaerobic process: Integrating chemical coagulation with simultaneous power production. *Bioresource Technology* 174: 142-151.

Ma, B., Peng, Y., Zhang, S., Wang, J., Gan, Y., Chang, J., Wang, S., Wang, S. & Zhu, G. 2013. Performance of anammox UASB reactor treating low strength wastewater under moderate and low temperatures. *Bioresource Technology* 129: 606-611.

Mahmood, Q., Ping, Z., Cai, J., Wu, D., Hu, B. & Li, J. 2007. Anoxic sulfide biooxidation using nitrite as electron acceptor. *Journal of Hazardous Materials* 147(1-2): 249-256.

Metcalf, L., Eddy, H.P. & Tchobanoglous, G. 1991. *Wastewater Engineering: Treatment, Disposal, and Reuse*. New York: McGraw-Hill.

Meyer, T. & Edwards, E.A. 2014. Anaerobic digestion of pulp and paper mill wastewater and sludge. *Water Research* 65: 321-349.

Mullen, M., Wolf, D., Ferris, F., Beveridge, T., Flemming, C. & Bailey, G. 1989. Bacterial sorption of heavy metals. *Applied and Environmental Microbiology* 55: 3143-3149.

Patel, A., Arora, N., Pruthi, V. & Pruthi, P.A. 2017. Biological treatment of pulp and paper industry effluent by oleaginous yeast integrated with production of biodiesel as sustainable transportation fuel. *Journal of Cleaner Production* 142: 2858-2864.

Pererva, Y., Miller, C.D. & Sims, R.C. 2020. Approaches in design of laboratory-scale UASB reactors. *Processes* 8: 734.

Rosa, A., Chernicharo, C., Lobato, L., Silva, R., Padilha, R. & Borges, J. 2018. Assessing the potential of renewable energy sources (biogas and sludge) in a full-scale UASB-based treatment plant. *Renewable Energy* 124: 21-26.

Tawfik, A., Bakr, M.H., Nasr, M., Haider, J., Lim, H., Qyyum, M.A. & Lam, S.S. 2022. Economic and environmental sustainability for anaerobic biological treatment of wastewater from paper and cardboard manufacturing industry. *Chemosphere* 289: 133166.

Van Lier, J., Van der Zee, F., Frijters, C. & Ersahin, M. 2015. Celebrating 40 years anaerobic sludge bed reactors for industrial wastewater treatment. *Reviews in Environmental Science and Bio/Technology* 14: 681-702.

Yeoman, S., Stephenson, T., Lester, J. & Perry, R. 1988. The removal of phosphorus during wastewater treatment: A review. *Environmental Pollution* 49: 183-233.

Zeng, T.T., Rene, E.R., Zhang, S.Q. & Lens, P.N.L. 2019. Removal of selenate and cadmium by anaerobic granular sludge: EPS characterization and microbial community analysis. *Process Safety and Environmental Protection* 126: 150-159.

Zwain, H.M., Aziz, H.A. & Dahlan, I. 2016. Effect of inoculum source and effluent recycle on the start-up performance of a modified anaerobic inclining-baffled reactor treating recycled paper mill effluent. *Desalination and Water Treatment* 57: 21350-21363.

Zwain, H.M., Hassan, S.R., Zaman, N.Q., Aziz, H.A. & Dahlan, I. 2013. The start-up performance of modified anaerobic baffled reactor (MABR) for the treatment of recycled paper mill wastewater. *Journal of Environmental Chemical Engineering* 1: 61-64.

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