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BORON REMOVAL FROM INDUSTRIAL WASTE WATER USING HYBRID ADSORPTION-MEMBRANE SYSTEM

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Abstract

The production of industrial wastewater containing heavy metals pollutants, including boron has caused a great deal of concern due to high concentration which is toxic and harmful to the environment. Several treatment technologies including, adsorption, electrocoagulation, chemical coagulation, chemical precipitation and membrane have been reported in eliminating boron from a generated effluent before discharge. The current study utilizes a hybrid system comprising of three compartments, namely adsorption, settling, and membrane compartment. Initially, at the adsorption section of the hybrid system, the [redacted] wastewater was subjected to adsorption process for 250 minutes, using nano-magnetite sorbent. The remedied effluent was examined, and a considerable performance was noticed in the removal efficiencies of boron, turbidity, copper, and zinc with 74.39 %, at 250

Keywords: Boron Removal, Waste Water, Hybrid Adosoption Membrane System, Industrial Waste Water, Hybrid.

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minutes contact time. Though, the sorbent was able to achieve 74.39% boron removal rate alongside with 2.2 mg/L concentration. However, this concentration is still above the WHO/EU/DOE (0.5-1.0 mg/L) standard limit. Application of further treatment process became imperative to meet the standard discharge limit. A nanocomposite membrane was employed as treatment process to improve the efficiency of boron removal. The contaminants removal rate for neat (PVDF-PVP) and modified (1.0 wt% TiO_2) membranes in respect to boron. The physicochemical analysis of the permeate revealed that the boron concentration was significantly reduced to 0.43 mg/L, which is far lower than the discharge limit of 1.0 mg/L. Finally, the modified hybrid TiO_2 membrane has demonstrated to be effective in relegating boron from the wastewater.

Introduction

Background of the study

Over the past years, continued commercial and industrial revolution in many nations around the world goes along with speedy increase in the generation of industrial and municipal solid wastes. This significantly leads to severe environmental, economic and health problems (Salehi et al., 2014). Various waste disposal methods, examples include sanitary landfill, open disposal, incineration, composting, hog feeding, grinding and anaerobic digestion are the most commonly practiced. There are some certain setbacks, which limits the application of these technologies. Due to its simplicity, landfilling is most extensively applied method of waste disposal in Malaysia (Aziz et al., 2010; Ismail and Manaf, 2013). Other category of landfill, including, open dumping, sanitary, and scheduled landfill, ie, waste generated from materials with hazardous characteristics which includes toxicity, flammability, explosively, corrosively and biological infectivity are also applied for waste disposal (Chaaban, 2001). Despite its wide acceptability, the generation of contaminated liquid (leachate) from landfill activities is a major concern, as it posed serious threat to environmental and public health safety (Kulikowska and Klimiuk, 2008).

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Leachate is a dark aqueous liquid produced because of rainwater passing over several layers of waste undergoing a series of decomposition phases (Abbas et al., 2009; Robinson, 2005; Wiszniowski et al., 2006). In Malaysia reports have shown that 54.8% of the schedule waste were usually moved into the landfill for final disposal (Aja & Al-kayiem, n.d.). Various factors including, location hydrology, landfill age, temperature, landfill depth, moisture content and refuse formation determines the leachate characteristics (Singa et al., 2018; Wang et al., 2004). As stated in commonly used legislation, leachate from landfill must be treated accurately prior to releasing into accepting water surface. Specifications like COD, BOD, BOD/COD ratio, pH, (SS), (NH_3-N), boron and heavy metals can represent the leachate characteristics(Adani, 2000; Lee et al., 2010). Consequently, remedying landfill leachate is necessary for mitigating environmental impacts and complying with statutory requirements before discharging into natural waterways. Ion exchange, chemical oxidation, chemical precipitation, activated carbon, adsorption and reverse osmosis are the various treatment technologies used to treat rebellious organic compounds from landfill leachate. Landfill leachate treatment technologies are categories into three main groups, namely, biological (aerobic or anaerobic), chemical and physical and combination of physical-chemical and biological processes (Gao et al., 2015a; Wiszniowski et al., 2006).

The industrial wastewater discharge are the primary sources for releasing boron to the environment. In Malaysia alone, about 2,918,478.34 metric tons of this wastewater were generated in the year 2015 and this estimation is expected to escalate due to the progressive increase in population (Aja & Al-kayiem, n.d.). This justifies the high tendencies of excessive concentration of boron. The boron concentration in natural water and wastewater is in the range of 0.3-100mg/L (Kluczka et al., 2015). However, the concentration may exceed 100mg/L depending on the geology of the surrounding and sewage disposal (Kluczka et al., 2015). In a national leachate survey, it was discovered that landfill leachates had significantly elevated boron concentrations (up to 84 mg/l) (Yoshinaga et., al 2001). The Department of Environment Malaysia and the World Health Organization (WHO) have set standards for boron concentration discharge limits in drinking water to be less than 1.0 mg/L and

0.5 mg/L, respectively, due to the possible adverse health effects on humans. (Aja & Al-kayiem, n.d.).

Investigations have revealed that associated high concentration of boron and other heavy metals in leachate causes acute vomiting, nausea, diarrhea, dermatitis and cardiovascular diseases (Donoiu et al., 2018). In addition, boron exhibit a noticeable effect on plants such as meristematic growth in tissues, disruption of roots and leaves, thickening of leaves, cracking of bark growth and interfering with cell formations, alongside with delaying in enzyme reactions (Chen et al., 2019; Patrick & Hening, 1997). Display of yellowish spots on leaves and fruits along with a rapid deterioration and untimely expiration of plants were all due to excess boron (Fujita et al., 2005). Therefore, the need for leachate treatment before the final discharge into the environment is imperative.

Various technologies have been exploited for the ejection of boron from water and wastewater. However, there are some drawbacks associated with the application of these methods, which limit their application. Among the various methods employed for boron removal, include chemical precipitation (Xu & Jiang, 2008), activated carbon(Chen et al., 2020a; Foo et al., 2013), electrocoagulation (Jiang et al., 2006; Jiang et al., 2006; Savas, 2007), chemical coagulation (Yilmaz et al., 2007) and reverse osmosis (Figueras & Borrego, 2010). The later method is considered most promising technique for boron removal because of its simplicity in operation and economical sustainability (Cengeloglu et al., 2008; Gao et al., 2011) Among the most sophisticated and versatile techniques for wastewater treatment, drinking and ultra-pure water production, water recycling, and desalination are membrane-based purification processes (Environ et al., 2011). However, its application is being limited by fouling which outturn in a reduction in flux and rejection. Blending in titanium dioxide nanoparticles (TiO_2) into membrane dope improve the hydrophilicity of the membrane, enhance flux and mitigate the fouling problem on the membrane surface (Bae & Tak, 2005; Oh et al., 2009). On this note,the present study incooperated TiO_2 nanoparticles into the membrane dope to make the membrane matrix structure hydeophilic and more negatively charge to remove boron from SWL. Moreso, the present research work is the first to utilize TiO_2 to remove boron from SWL

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Owing to the various difficulties and economic disadvantages of those technologies, it has necessitated researchers to conduct new investigations to produce a robust and economical method that will remove boron from water and wastewater effectively. In view of this, the current study focused on developing a system of adsorption membrane to remove boron and metals of interest such as Zn and Cu industrial wastewater. Boron chosen based on its industrial applications and potential pollution impact on the environment.

Materials and Method

Sampling and Characterization of Wastewater Sample

Industrial wastewater sample was collected in a confined container from industrial site. The sample was taken and preserved in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 2005). The sample was immediately transported to the Laboratory and preserved in a chiller at 4 °C. Selected parameters such as pH, BOD_5, COD, NH_3-N, color, Turbidity, TSS, TDS, Cu, Zn, Fe and B were investigated based on the Standard Method for the Examination of Water and Wastewater (APHA, 2005).

Chemicals and Instruments used

Boron ver 3 reagents, concentrated H_2SO_4 solution, Deionized water, pipetted and burr ate, conical flask, cell holder, UV-vis spectrophotometer (DR/4000u), System Milli-Q water (18 MO cm).

Analytical Method

The continuous hybrid system study, investigated investigated based on the Standard Method for the Examination of Water and Wastewater (APHA,2005). These parameters were analyzed using the UV-spectrophotometer (HACH DR/400U) at an absorbance wavelength of 605, 560, 620 and 860 nm, respectively. Basically, carmide method 8015 was used to analyze boron concentration before and after treatment. The choice of this method was due to its accuracy and simplicity.

Boron

Boron was determined by carmine method 8015 at a wavelength of 605 nm (40). The process of determining boron concentration involves adding Boron

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ver 3 reagents into a 75 ml concentrated H_2SO_4 solution. After 5 minutes reaction, 2 ml of sample and deionized water was accurately pipetted into 125 ml flask each. In each flask, 35 ml of boron ver 3/H_2SO_4 solution was added. The prepared sample was placed into the cell holder of the UV-vis spectrophotometer (DR/4000u) at the wavelength of 620 nm. All Deionized water utilized in the batch experiments was obtained from the purification system Milli-Q water (18 MO cm). The adsorption capacity q_e (mg/g) and removal efficiency Re (%) of boron were calculated using equation (1) and (2) respectively.

$$q_e = \frac{(C_O - C_F)V}{M} \quad 1$$

C_o and C_f are the initial and equilibrium concentration of boron in the sample (mg/L).

q_e Is the equilibrium boron concentration (mg/g), M is the adsorbent mass (g) and V (L) is the volume of the boron from a stock solution.

The percentage removal of boron was calculated using equation (2).

$$\text{Re}\ (\%) = \frac{C_O - C_F}{C_O} \times 100 \quad 2$$

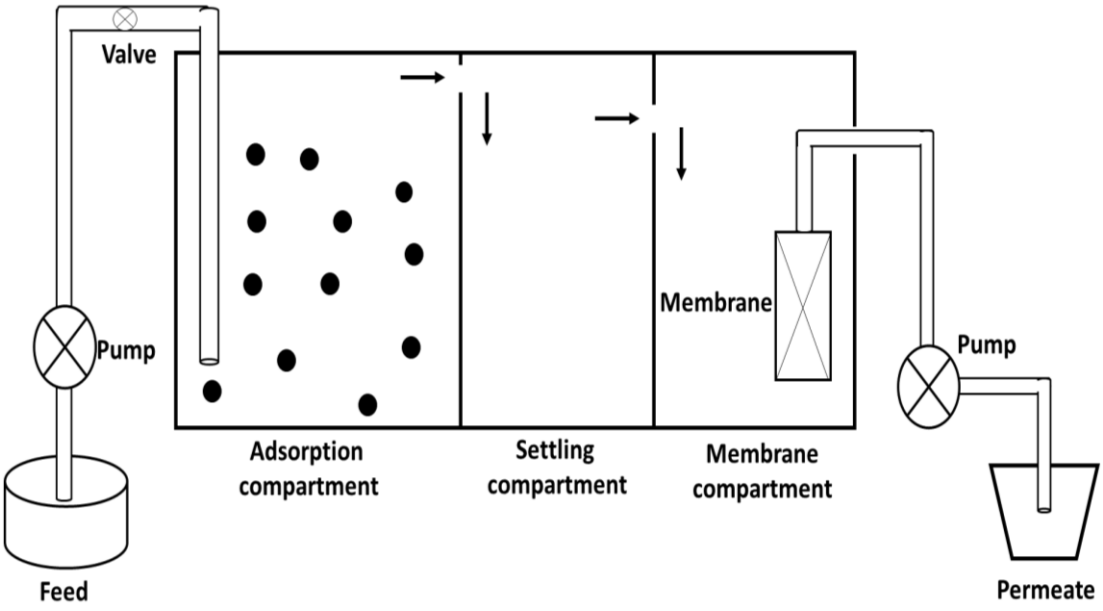


Figure 1: Schematic diagram of adsorption membrane system

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Results and Discussion

Physical-chemical and Biological Characteristics of Wastewater Sample

Table.1 presents the physicochemical characteristics of the SWL used the present study. It was observed from Table 1 that the concentration of boron has significantly exceeded the DOE standard. Therefore, the need for its treatment before the final discharge into the environment is imperative.

Table. 1: Characteristic of Wastewater Sample

Parameter	Average Value	DOE Standard A
pH	9.59 ± 0.05	5.5-9.0
TSS	426.67 ± 15.5	100
Turbidity	321.67 ± 8.5	NA
COD	2256.67 ± 100.5	200
Boron	8.2 ± 0.55	1.0
Zinc	1.06 ± 0.35	2.0
Color	229 ± 3.5	200

(Department of Environment, 2010) *All units are in mg/L except pH

Contaminants Removal Efficiencies

The removal percentage efficiencies of the contaminant from wastewater were summarized in Table 2. Four different contaminants were identified and removed using the physical treatment process of adsorption. There were significant differences ($p < 0.05$) among all contaminants subjected to varying treatment times. Generally, as treatment time progresses, the removal efficacy also improves; thus, there was not much difference ($p > 0.05$) for time 200 and 250 min. The effectiveness of the adsorption process was higher in > B. Though, the sorbent was able to achieve 74.39% boron removal rate and 2.2 mg/L concentration. However, this concentration is above the WHO/EU/DOE (0.5-1.0 mg/L) standard limit. Application of further treatment process became imperative to meet the standard discharge limit. On this note, the treated effluent was moved to the membrane compartment for further polishing.

Table 2: % Boron; Turbidity; Copper; Zinc Removal efficiency (means ± SEM)

Parameters	Time					
	50	100	150	200	250	P value
B	65.85 ± 0.70^{d}	69.51 ± 0.70^{c}	71.54 ± 0.41^{bc}	73.17 ± 0.70^{ab}	74.39 ± 0.70^{a}	<.0001

a,b,c.. Means on the same raw carrying same superscripts are not significantly different. $P < 0.05$

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Boron Removal by Membrane

The removal of hazardous boron from water is an important issue for the environmental point of view. As shown in Figure 1, under steady scouring aeration of 5 L/min boron removal efficiency by the neat membrane is compared with the modified membrane. It can be seen from Figure 1 that after 20 min filtration period, the neat membrane had 76.70% removal efficiency with a corresponding concentration of 1.91 mg/L. The boron removal efficiency eventually stabilizes at 320 min filtration time with 73.78 % removal efficiency. Interestingly, the modified membrane had higher boron removal rate of 94.87% with a corresponding concentration of 0.42 mg/L which is significantly lower than the standard discharge limit stipulated by WHO 1.0 mg/L (World Health Organization, 2006). After 300-minute filtration time, the removal efficiency remains stable with 93.04% efficiency. In Figure 4.31 there is a clear trend of decreasing boron removal rate as the filtration duration increases. In summary, the modified membrane exhibited a better boron removal performance due to hydrophilic effect and inducement of zeta potential by in cooperating Nano-TiO_2 as an influential additive. The findings of the current study are in consistence with those of (Alharati et al., 2017; Kabay et al., 2008, 2009)

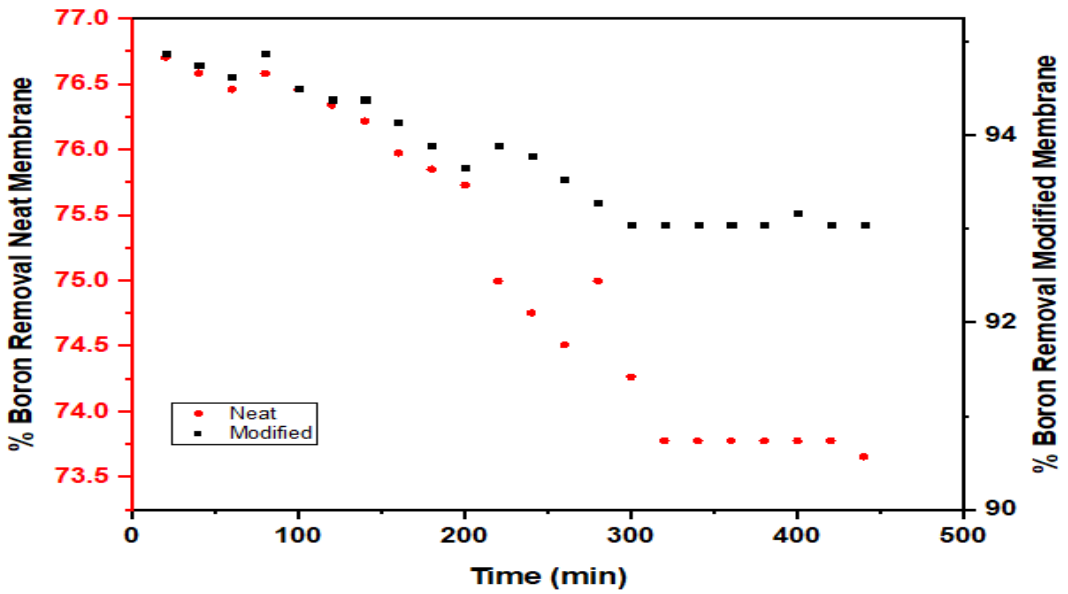


Figure 1: Profile of boron removal performance of neat (red) and modified membrane (black)

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