

## Advanced tertiary treatment of municipal wastewater using raw and modified diatomite

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### Abstract

Advanced technology for more efficient and effective wastewater treatment is always timely needed. The feasibility of using raw and modified diatomite for advanced treatment of secondary sewage effluents (SSE) was investigated in this study. Raw diatomite at a dosing rate of 300 mg/l showed a similar potential as activated carbon for removing most organic pollutants and toxic metals from SSE. Its performance was found poor in removal of arsenic and crop nutrient constituents (e.g. ammoniacal nitrogen and phosphate) and remained unsatisfactory even when the dosing rate increased up to 500 mg/l. Where modified diatomite was in lieu of raw diatomite, the removal efficiency for all target constituents was improved by 20–50%. At the dosing rate of 150 mg/l, modified diatomite enabled the post-treated effluents to satisfy the discharge consents, with the levels of all target constituents below the regulatory limits. Modified diatomite has advantages over raw diatomite in improving removal efficiency and reducing the dosing rate required for satisfactory treatment of SSE. It is concluded that modified diatomite is much more effective and efficient than raw diatomite, as an alternative to activated carbon, for economic treatment of SSE.

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### 1. Introduction

Disposal of improperly treated wastewater often poses risk to the environment and ecology. Using advanced technology to mitigate risk by refined wastewater treatment is a key issue in meeting legislative guidelines, e.g. EU Water Framework Directive. Municipal wastewater treatment typically comprises preliminary treatment, primary treatment and secondary treatment. Preliminary treatment includes a series of screens and grit removal to prepare wastewater for subsequent treatment. Primary treatment involves the separation of readily-removable suspended solids through gravity sedimentation. Following these two basic processes, wastewater is then subjected to secondary treatment in which biological and/or chemical processes are involved to remove dissolved constituents. The secondary treatment

was previously considered as a complete process, with its effluent being discharged into the receiving environment after disinfection with chlorine gas [1]. However, as environmental regulations are getting stringent and introduction of EU Water Framework Directive in 2000 [2], secondary sewage effluent (SSE) was no longer a guarantee for discharge [3]. Advanced tertiary treatment is therefore, required for further decreasing the residual constituents in SSE.

A variety of technologies have been developed and applied for the treatment of SSE. The commonly used techniques include membrane filtration with the aid of coagulants, chemical oxidation and precipitation, activated carbon adsorption and constructed wetland [4]. Activated carbon adsorption has been held to be a particularly competitive and effective process in removing organic and inorganic constituents from the waste effluents [5–7]. However, activated carbon is less economically viable as an adsorbent due to the costly activation and regeneration of the spent carbon and disposal

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of regenerant wastes. As a result, over recent years there has been growing interest in using low-cost natural minerals for treating wastewater. Among these minerals is diatomite.

Diatomite, also referred to as diatomaceous earth, is durable, extremely lightweight and highly porous; it has a large surface area of 50–200 m<sup>2</sup>/g [8]. It consists primarily of the fossilized skeletons of diatoms, which were once marine planktons and algae. There were isolated and H-bonded hydroxyl groups detected on the surface of diatomite [9]. As a result of its unique physical and chemical properties, diatomite has been put in industrial application as filtration media for various beverages [10]. A number of laboratory-scale studies were also performed to investigate the potential of diatomite as an adsorbent for removing waterborne radionuclides, e.g. uranium [11], heavy metal ions, e.g. Pb<sup>2+</sup>, Cu<sup>2+</sup> and Cd<sup>2+</sup> [12,13] and basic textile dyes [14,15] from wastewater. While these studies have demonstrated promising outlook of diatomite for wastewater treatment, most of them were focused on individual constituent or a limited number of toxic metals in synthetic wastewater. It is poorly understood whether diatomite can be applied for treating the real waste effluent that contains a wide range of organic and inorganic constituents.

The objectives of this study were to (i) identify the feasibility of using raw diatomite as an alternative to activated carbon for tertiary treatment of municipal wastewater and (ii) investigate whether the removing efficiency of the target constituents from SSE could be improved by using chemically-modified diatomite. To achieve these objectives, two treatment systems were involved: a laboratory-scale system, i.e. batch reactor system (BRS); a pilot-scale system, i.e.

continuous flow system (CFS). The comparison in treatment efficiency between these two systems was established.

## 2. Methods and materials

Materials used in this study involved raw diatomite, modified diatomite, powdered activated carbon and wastewater samples. Raw diatomite powder was provided by Yunnan Qingzhong Environmental Co. Ltd., China. According to manufacturer's information [16], diatomite was produced by milling diatomaceous sedimentary rock, and then refined and purified using a low-cost physical method instead of conventional expensive technique (i.e. acid washing). The refined diatomite contains 98% diatoms, which have honeycomb structure (Plate 1) and particle size ranging from 40 to 200 μm. Chemical analyses of diatomite composition showed 84.2% SiO<sub>2</sub> (of which non-crystalline SiO<sub>2</sub> 97.5% and crystalline SiO<sub>2</sub> 2.5%), Al<sub>2</sub>O<sub>3</sub> 6.51%, Fe<sub>2</sub>O<sub>3</sub> 5.23% and CaO 1.32%.

The chemically-modified diatomite was prepared by placing raw diatomite powder with solid aluminum sulfate and lime at the ratio of 6:1:3 in a mixing bowl, stirring for 20 min at 100% moisture of distilled water. This was followed by treating the mixed samples in an ultrasonic bath for 15 min and then oven drying at 60 °C. The oven dried samples were ground through a 100-mesh sieve, and charred in Muffle furnace at temperature of 450 °C for 2 h.

Powdered activated carbon (PAC) was obtained by grinding through a 100-mesh sieve the commercial granule activated carbon manufactured by Xinsen Chemical Industry

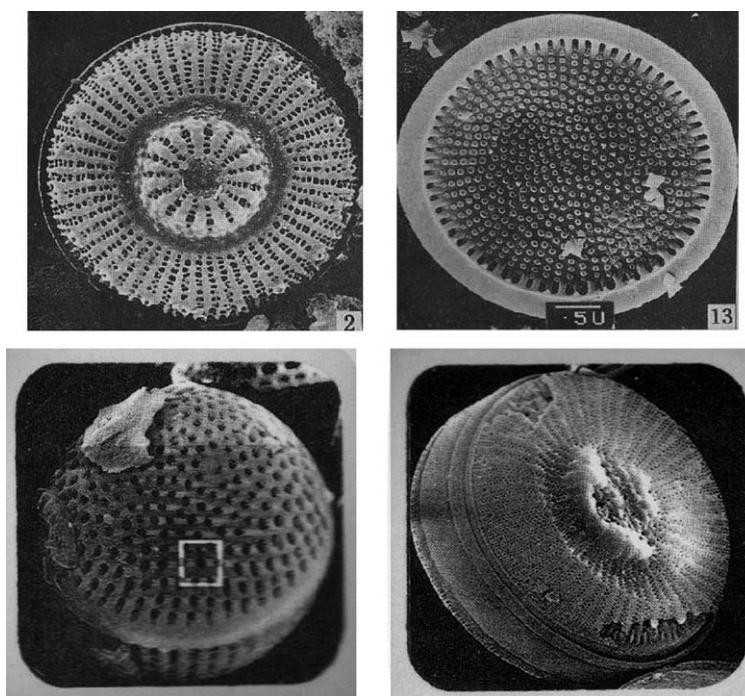


Plate 1. Honeycomb structure of diatom skeletons in different shapes.

Co. Ltd., China. Both diatomite and PAC were stored in polyethylene containers. Wastewater samples were collected on a batch sampling basis from SSE. A composite sample was prepared by mixing several batch samples, and then brought to laboratory and kept in fridge at temperature of 4 °C for subsequent tests and experiments.

### 2.1. Treatment systems

Two treatment systems were designed in this work. One is a BRS that comprises of a 1500 ml glass jar and a speed-control stirrer. This system is simple in operation and time-saving when performing a large number of tests. The other is a CFS, which was designed to enable the mineral-bearing sludge to be drained without stopping the flowing water. As shown in Fig. 1, this system consists of Teflon tubes with various diameters, pumps, a spray nozzle, two settling tanks and one reaction tank with a trapezoidal shape bottom. These tanks were constructed using galvanized iron sheets, with effective dimension of 220 mm × 120 mm × 250 mm (long × wide × deep) for the reaction tank and 120 mm × 120 mm × 200 mm for the settling tanks.

### 2.2. Treatment procedure and sampling

A batch experiment was carried out by transferring 1000 ml SSE sample (kept in fridge) into a 1500 ml jar, mixing with 150 mg diatomite and leaving it to bring water

temperature up to circa 20 °C (i.e. room temperature). The stirrer was then turned on at speed of 400 rpm; the solutions were left to stand for 120 min after stirring. Following this, 100 and 400 ml samples were separately collected from the jar using a siphoning tube at 15–20 mm below the surface of upper clarified supernatant. Hundred millilitres sample was filtered through a 0.45 μm paper filter. Filtered solid was subjected to oven-drying at 105 °C for the determination of suspended solids, while the filtrate was acidified and stored in fridge for subsequent analysis of toxic metals. Other 400 ml sample was used for an immediate determination of inorganic nutrients, 5-day biochemical oxygen demand (BOD<sub>5</sub>) and chemical oxygen demand (COD). The batch experiment was repeated but with the stirring time being reset at different periods in order to establish an adequate stirring time for a maximum adsorption capacity.

Once the adequate stirring time was established, adsorption dosage studies were performed following the same procedure stated earlier. Diatomite was operated at six desired dosing rates (i.e. 50, 100, 150, 300 and 500 mg/l), respectively including a control test.

Treatment in a CFS was conducted by pumping the SSE sample with a peristaltic pump and mixing with diatomite at the desired dosage through an aeration tank, and spraying via a fine nozzle into air to produce very small water droplets (see Fig. 1). The diatomite-bearing droplets fell into the tank in a way similar to fountain water spray. When diatomite particles in the aeration tank settled down towards the bottom, most of them were pumped up again to spray into the air by a negative

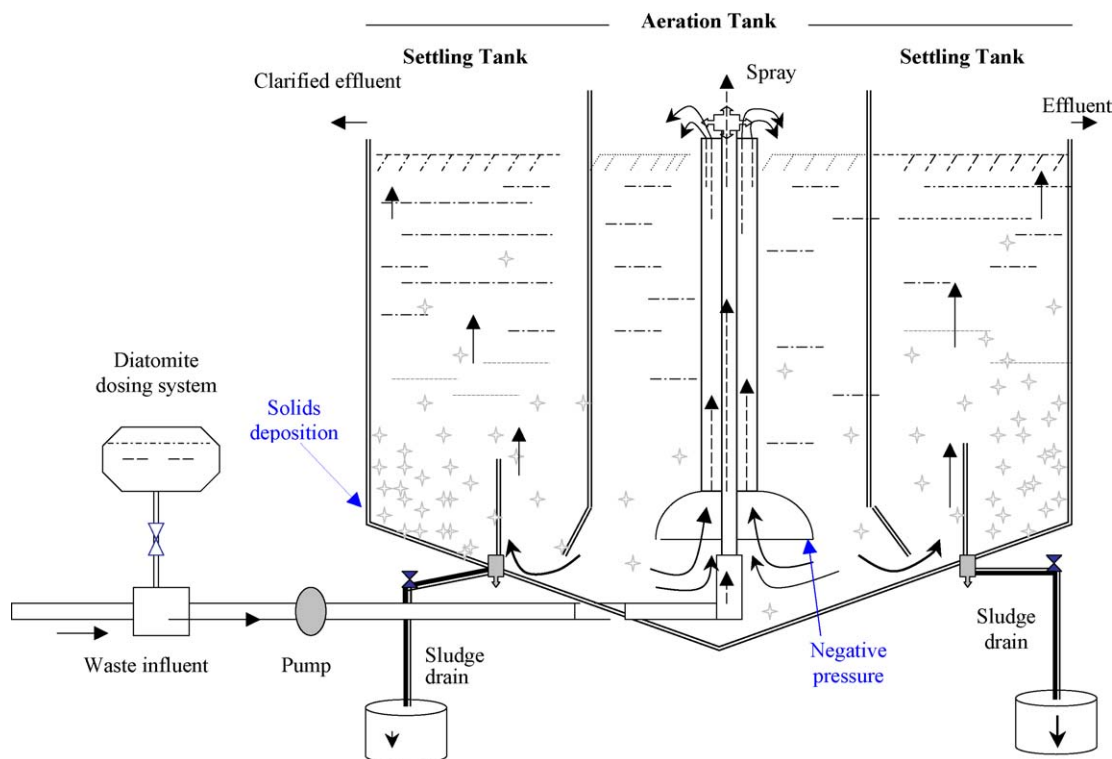


Fig. 1. Schematic diagram of continuous flow treatment system.

pressure applied to the bottom. This circulation resulted in the agitation and aeration of mixed solution in the tank, leaving diatomite fully in contact with constituents and leading to the emission of volatile organic compounds (if any) into air.

As illustrated in Fig. 1, part of the mixed solution flowed from the bottom of the aeration tank to the lateral settling tanks where solid and liquid were separated. Up-flowing water in the settling tank was controlled at a speed of 1.5–2 mm/min by adjusting the flow rate of wastewater into the aeration tank, with hydraulic retention time of circa 1.5–2 h. This allows the mixed solution having sufficient time for developing a distinct interface between settling particles and clarified liquid. Water samples for quality monitoring were collected from the clarified effluent overflowing the settling tank, whilst waste sludge was drained from the bottom of the settling tanks.

### 2.3. Chemical analysis and removal efficiency

Eleven target constituents and pH were selected as parameters for water quality assessment. These include suspended solid (SS), chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD<sub>5</sub>), three nutrient constituents (ammoniacal nitrogen, total nitrogen and total phosphorus) and five toxic metals (arsenic, cadmium, lead, copper and zinc). Ammoniacal nitrogen (NH<sub>4</sub>-N) was determined using a Kjeldahl method [17]. Total nitrogen (TN) was worked out by summing total Kjeldahl nitrogen (i.e. organic nitrogen and free ammonia) and nitrate that was determined by ion chromatography. Total phosphorus (TP) was measured with a colorimetric method following acid digestion of water samples. Toxic metals were determined using ICP-MS. A dichromate method was used for the determination of COD. For BOD<sub>5</sub>, water samples were incubated for 5 days at temperature of 20 °C and BOD<sub>5</sub> was determined based on the difference between the initial dissolved oxygen (DO) and final DO. Details about the determination of these constituents are given by Radojević and Bashkin [17].

The removal efficiency ( $R_e$ ) was calculated by  $R_e = 100(C_0 - C_e)/C_0$ , where  $C_0$  is the initial concentration of target constituent and  $C_e$  is the post-treated concentration of target constituent.

## 3. Results

### 3.1. Water quality of raw samples

Water samples, collected from the SSE of a municipal wastewater treatment plant in China, were subjected to pH determination and analyses for 11 target constituents. The results are presented in Table 1. A comparison of these results with regulatory limits for discharge [18,19] shows that except pH, all target constituents are over the limits. Therefore, SSE is not suitable for direct discharge into the natural aquatic environment, unless further advanced treatment is carried out.

Table 1  
Water quality parameters and discharge consent standards (DCS)

Parameters	COD <sub>Cr</sub> (mg/l)	BOD <sub>5</sub> (mg/l)	SS (mg/l)	NH <sub>4</sub> -N (mg/l)	TN (mg/l)	TP (mg/l)	pH	As (mg/l)	Cd (mg/l)	Pb (mg/l)	Cu (mg/l)	Zn (mg/l)
Sample	148	61	56	35	52	5.2	6.42	0.18	0.1	1.7	11	16
DCS-China	60	20	20	12	20	1.5	5.5–8.5	0.1	0.01	0.1	0.5	1
DCS-EU	125	25	35	10	15	1	5–9	N/A	N/A	N/A	N/A	N/A

Note: DCS-China (GB18918-2002, class B [19]); DCS-EU (91/271/EEC [18]). N/A: not available.



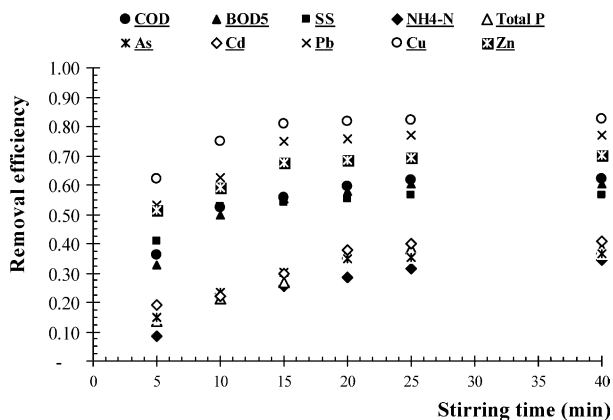


Fig. 2. Removal efficiency as a function of stirring time ( $t$ ).

### 3.2. Determination of adequate stirring time

A number of tests on a fixed dosing rate of diatomite were performed in batch reactors to establish the effect of stirring time on removal efficiency. The diatomite was fixed at 150 mg/l and the stirring speed at 400 rpm. The stirring time was set at 5, 10, 15, 20, 25 and 40 min, respectively. Based on the results from the analyses of clarified water samples, the removal efficiency for each of 11 target constituents was determined. A plot of the removal efficiency versus the stirring time was constructed and shown in Fig. 2.

Fig. 2 shows that the COD removal efficiency was greatly increased from 36% at  $t = 5$  min to 52% at  $t = 10$  min. Thereafter a gradual increase was found with the increasing stirring time; there was no significant improvement beyond 25 min. A similar pattern was observed for BOD<sub>5</sub>, SS, NH<sub>4</sub>-N and TP. This indicates that a maximum adsorption of these constituents onto diatomite was achieved after stirring for 25 min. As also shown in Fig. 2, removal of copper, lead and zinc was enhanced by about 35% as the stirring time extended from 5 to 15 min, but appeared independent of the stirring time over 15 min. In contrast, arsenic and cadmium had a steady increase in removal efficiency with increasing stirring time until the time reached 25 min. It follows that the stirring time set at 25 min is adequate for achieving maximum removal by raw diatomite in this study.

### 3.3. Treatment in batch reactors

The SSE samples were placed in the batch reactors and mixed with raw diatomite at the dosage of 50, 100, 150, 300 and 500 mg/l, respectively. The stirring time was set at 25 min as discussed above. A control test (i.e. without diatomite involved) was also conducted for comparison purpose, which showed little change in water quality as compared to the original SSE. Measurement of pH in post-stirred solutions revealed a progressive decrease from 6.40 to 6.05, as the dosing rate increased from 50 to 500 mg/l. Analyses of the clarified supernatant samples yielded the concentrations of 11 target constituents, based on which the removal efficiency

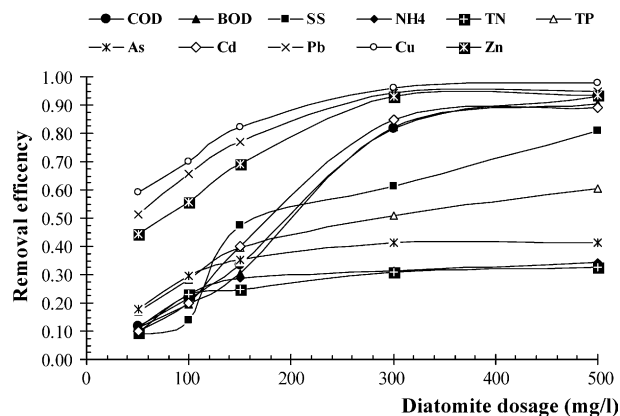


Fig. 3. Variation in removal efficiency with various diatomite dosages.

was calculated. The variation in removal efficiency as a function of diatomite dosing rate is shown in Fig. 3.

Fig. 3 shows that 60% of the dissolved copper, 50% lead and 45% zinc were removed from wastewater by raw diatomite at the initial level of 50 mg/l. In contrast, only 10% of the dissolved cadmium and 18% of the dissolved arsenic were removed. As diatomite dosing rates increased up to 300 mg/l, the removal efficiency was found to be 96% for Cu, 94% Pb, 92% Zn, 85% Cd, whilst only 41% for As. It demonstrated the highest removal efficiency for Cu, then Pb, Zn, Cd and As. When diatomite was dosed at 500 mg/l, no significant improvement was observed in metal removal.

As also shown in Fig. 3, COD and BOD<sub>5</sub> have a similar removal pattern as cadmium, with the removal efficiency as low as 10% at the dosing rate of 50 mg/l and quickly increasing up to 90% at 300 mg/l. The removal efficiency for SS is less than 15% at 100 mg/l, but rises rapidly to 50% at 150 mg/l and then shows a gradual increase to 80% at 500 mg/l. As far as crop nutrient removal is concerned, only 10–30% of TN and NH<sub>4</sub>-N and 20–60% of TP were removed by raw diatomite at the dosing rate ranging from 50 to 500 mg/l. All these data give an indication that raw diatomite have comparatively low adsorption capacity for nutrients and arsenic.

### 3.4. Treatment with powdered activated carbon

A test on SSE using powdered activated carbon (PAC) was conducted in a batch reactor at the dosing rate of 300 mg/l. The purpose for this test was to identify the difference in adsorption capacity between PAC and raw diatomite with same dosage. Results are presented in Fig. 4.

It shows that 65% SS and over 90% copper, cadmium, lead and zinc were removed by PAC. The removal efficiency for COD and BOD<sub>5</sub> was found to be 85%. A comparison between diatomite and PAC demonstrates that raw diatomite have similar adsorption capacity and removal ability for heavy metals, SS, COD<sub>Cr</sub> and BOD<sub>5</sub> as PAC. However, it is completely different for nutrients and arsenic, with removal efficiency of about 75% TN and NH<sub>4</sub>-N, 80% TP, 50% arsenic by PAC, compared to 35% TN and NH<sub>4</sub>-N, 50% TP and 40%

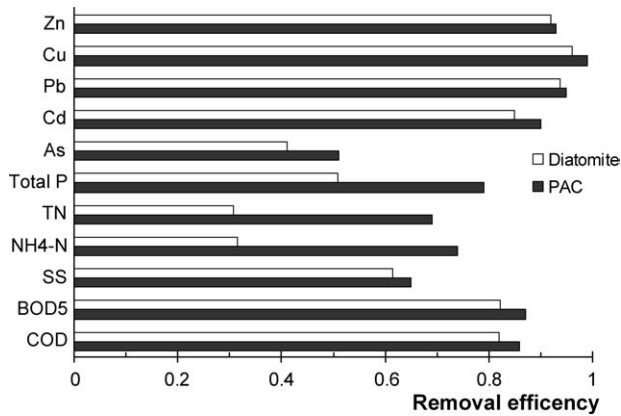


Fig. 4. Comparison in removal efficiency between diatomite and PAC.

arsenic by raw diatomite. Therefore, PAC is more effective in removing crop nutrients and arsenic from wastewater than raw diatomite.

3.5. Treatment in CFS

Raw diatomite mixed with SSE at dosage of 300 mg/l was pumped into an aeration tank, and sprayed into air via a fine nozzle, as shown in Fig. 1. Water samples were collected from the clarified water overflowing the settling tanks and undertaken water quality analyses. Results are given in Fig. 5. For comparison, shown in Fig. 5 are also the results from raw diatomite dosed at 300 mg/l in the BRS.

The removal efficiency in CFS is 80% for COD and BOD, 60% SS, 50% TP, 40% arsenic and over 85% for other toxic metals. The removal efficiency for all target constituents is similar to that in BRS, with an exception of ammoniacal nitrogen and total nitrogen. The CFS had 45% NH<sub>4</sub>-N and 40% TN removed from wastewater, whilst 30% NH<sub>4</sub>-N and TN in BRS. The slightly higher removal efficiency for nitrogen in CFS may be due to the spraying aeration leading to a fraction of ammoniacal nitrogen emitting into air.

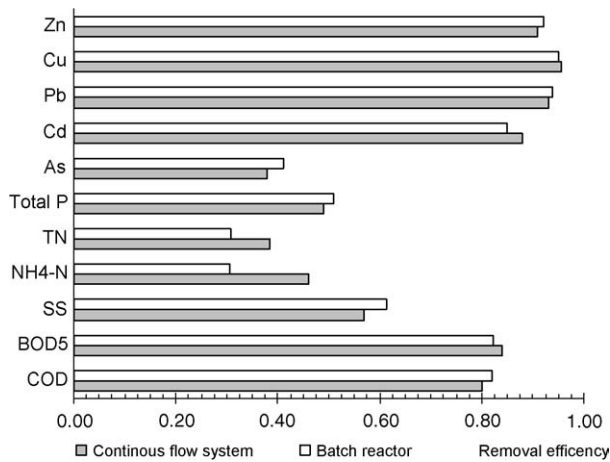


Fig. 5. Comparison in removal efficiency with raw diatomite at 300 mg/l between the CFS and BRS.

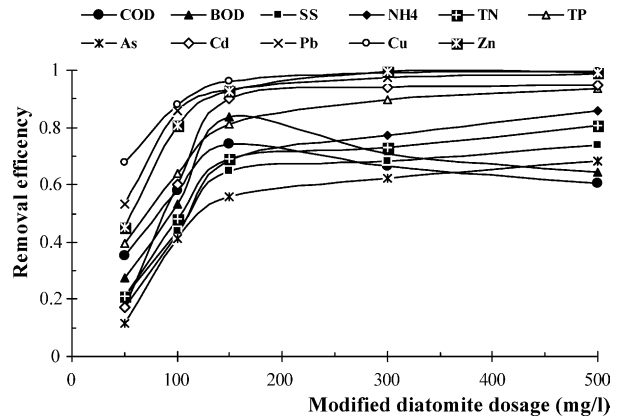


Fig. 6. Variation in removal efficiency with dosages of modified diatomite.

3.6. Treatment using modified diatomite in CFS

Treatment with modified diatomite was carried out in the continuous system, following the same operating procedure as stated earlier. The modified diatomite consists of 60% raw diatomite, 30% lime and 10% aluminum sulphate. The dosing rates were applied at 50, 100, 150, 300 and 500 mg/l, respectively. Measurement of pH in the solutions of the aeration tank showed no difference from that in the clarified water overflowing the settling tanks. An increase in the dosages of modified diatomite increased the pH in solutions, with pH 6.65 at dosage of 50 mg/l and 7.08 at 150 mg/l, 7.62 at 300 mg/l and 8.35 at 500 mg/l. Analytical results for clarified water are shown in Fig. 6.

The removal efficiency was 12% for arsenic, 68% copper and 15–50% for other toxic metals with modified diatomite at 50 mg/l. It was enhanced significantly as the dosing rate increased to 150 mg/l, with over 90% of target toxic metals (except arsenic) being removed from wastewater. As also shown in Fig. 6, 80% TP, 70% nitrogen nutrient, 75% COD, 85% BOD<sub>5</sub> and 65% SS were removed by modified diatomite at 150 mg/l. When increasing the dosages over 150 mg/l, there was a slight increase in the removal rate for most target constituents. An exception for COD and BOD<sub>5</sub> was found; their removal rates decreased when the dosing rates greater than 150 mg/l.

A comparison between modified diatomite (Fig. 6) and raw diatomite (Fig. 3) at the dosing rate ≤150 mg/l shows that the former has higher removal rates, 20–50% higher, than the latter for all target constituents. This indicates that the modified diatomite performed much better than raw diatomite in the SSE wastewater treatment.

3.7. Water quality after treatment

The concentrations of target constituents in the post-treated water are summarized in Table 2. For simplicity, presented in the table are only results from the treatment at the dosing rate of 300 mg/l. The concentrations of NH<sub>4</sub>-N, TN, TP, As and Zn in the post-treat water from both BRS

Table 2  
Concentrations of target constituents and pH after treatment at the dosing rate of 300 mg/l

	Parameters (mg/l)											
	pH	COD <sub>cr</sub>	BOD <sub>5</sub>	SS	NH <sub>4</sub> -N	TN	TP	As	Cd	Pb	Cu	Zn
Raw diatomite												
BRS	6.08	27	11	22	24	36	2.6	0.12	0.01	0.09	0.40	0.95
CFS	6.12	30	10	25	19	32	2.7	0.11	0.01	0.11	0.45	1.02
Modified diatomite												
PAC	7.62	49	18	18	8	14	0.55	0.06	0.01	0.04	0.10	0.09
	6.25	20	8	20	9	16	1.1	0.08	0.01	0.08	0.10	0.98

and CFS with raw diatomite were above the regulatory limits (see Table 1). This suggests that water quality after treatment with raw diatomite failed to meet the discharge standards. However, the quality of water from the treatment with PAC and modified diatomite can meet the discharge standards; the concentrations of all target constituents except Cd are below the regulatory limits.

#### 4. Discussion

The SSE in this study had pH close to the neutral value. When it was mixed with raw diatomite, a slight decrease in pH occurred due to a release of hydrogen ions from raw diatomite associated with the adsorption of toxic metals via ion exchange processes. However, an increase in pH was detected when SSE was treated with modified diatomite which depends upon the dosing rates of modified diatomite. The increase of pH with the dosing rates may result from hydroxyl ions contributed by the lime from the chemical modification of diatomite.

A number of toxic metals were detected in SSE, including arsenic, cadmium, copper, lead and zinc. These toxic metals were removed to various extents when SSE was treated with diatomite. Copper appeared most ready for removal; arsenic was difficult to be removed in contrast. Their removal efficiencies were decreased in the following orders: copper, lead, zinc, cadmium and arsenic (Figs. 2 and 3). The low removal efficiency for arsenic was due to the poor adsorption of SSE-born arsenate/arsenite anions onto diatomite particles. The comparatively higher removal rate for copper can be associated with the smaller hydrated ionic radius of copper than that of other toxic metal ions [20], which facilitates its access to the micropores of diatomite.

SSE is not suitable for discharge because the target constituents are above the regulatory limits (Table 1). After treatment with raw diatomite in batch reactors, the levels of the constituents in the clarified water were reduced due to their adsorption onto diatomite particles. With increase of the dosing rate, the surface areas for adsorption were increased, thus leading to an increase in removal efficiency (Fig. 2). When raw diatomite was dosed at 300 mg/l in the reactor, all target constituents in the post-treat water were below the regulatory limits (Table 2), except crop nutrients (e.g. NH<sub>4</sub>-N and TP) and arsenic. Similar results were obtained when SSE was

treated in CFS. Removal of nutrients and arsenic remained unsatisfactory even at dosing rate of 500 mg/l, which indicates that raw diatomite is less effective in removing nutrient and arsenic from the SSE wastewater.

When powdered activated carbon (PAC) was in lieu of raw diatomite at the dosing rate of 300 mg/l, all target constituents were reduced to a satisfactory level with regard to regulatory discharge consent standards [18,19]. Clearly, PAC showed much higher effectiveness than raw diatomite in adsorbing and removing nutrients and arsenic (Fig. 4). The reason behind this could be that PAC removes nutrients and arsenic via chemical adsorption processes, whereas raw diatomite does them via physical adsorption processes. It has been demonstrated that contaminants adsorbed onto solid adsorbents via physical processes are weaker and more ready to be desorbed than those via chemical processes [21]. The physical adsorption is made through van der Waals force; whilst the chemical adsorption is through the formation of chemical bonds.

Treatment of SSE with modified diatomite in CFS showed higher removal efficiency for all target constituents (Fig. 6), as compared to that with raw diatomite in BRS (Fig. 3). Nutrients and arsenic were readily removed with modified diatomite. There is no significant difference detected between CFS and BRS in removing the target constituents except nitrogen (Fig. 5). CFS was also in favour of ammoniacal nitrogen removal due to the spraying aeration.

As raw diatomite was chemically modified with lime and aluminum sulfate, such modification might lead to aluminum-hydroxyl groups “transplanted” onto the surface of diatomite and thus facilitated removal of negatively charged-constituents (e.g. phosphate and arsenate) via chemical adsorption and coagulation. In addition, an increase in pH by lime addition could also play a part in enhancing the removal of ammoniacal nitrogen and toxic metals. However, it should be noted that the removal rate for COD and BOD<sub>5</sub> was decreased at higher dosing rates of modified diatomite (Fig. 6), which could result from increase of pH. According to West et al. [22], an increase in pH above 8.0 would decrease the adsorption of the dissolved carbon onto clay minerals.

As far as the disposal of wasted diatomite is concerned, it has been found useful as material for making brick and road construction following dewatering and drying [16]. Workers handling powdered diatomite should wear protective clothes,

dust masks and gloves to protect their health from any potential harm caused by diatomite via the pathways of skin contact and respiration.

## 5. Conclusions

Advanced treatment of SSE using raw diatomite and chemically modified diatomite was investigated. Following conclusions have been made:

- A slight decrease in pH was detected in the raw diatomite treatment. The maximum removal efficacy was achieved when stirring time was set at 25 min. The order of removal efficiency is copper > lead > zinc > other constituents.
- An increase in the dosing rate improved the removal efficiency. Raw diatomite has similar potential as powder activated carbon for removing COD, BOD<sub>5</sub>, suspended solid, copper, lead, zinc and cadmium, but poor performance for arsenic and nutrient constituents (e.g. ammoniacal nitrogen, total nitrogen and total phosphorus).
- Chemically modified diatomite can increase pH, significantly improve removal efficiency for all target constituents including arsenic and nutrients in the SSE treatment, as compared to raw diatomite. The dosing rate for achieving the discharge consent standards was also reduced largely, with only 150 mg/l required. Modified diatomite is thus considered much better than raw diatomite, as a low-cost alternative to activated carbon, for the effective treatment of SSE. However, as pH increases beyond 7.5, the efficiency for removing COD and BOD<sub>5</sub> could be reduced.
- There is no significant difference between BRS and continuous system in the SSE treatment. The former is simple, easily operated and suitable for quick tests; whilst the latter has an advantage of treating a large volume of wastewater and enabling the diatomite-bearing sludge to be drained without stopping the operation.

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