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ORIGINAL ARTICLE

Tofu wastewater treatment using vetiver grass (*Vetiveria zizanioides*) and zeliac

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Abstract
Tofu production is a domestic industry, that most of it has no appropriate wastewater treatment facilities. Wastewater of tofu contains high organic matter which can decrease the water quality. This study aimed to analyze capability of *Vetiveria zizanioides*, L and zeliac in treating tofu wastewater industry. Zeliac is a new adsorbent, which consists of zeolite, activated carbon, limestone, rice husk ash and cement. Response surface methodology was applied to analyze the data, using central composite design with two factors, i.e., time (3, 9, and 15 days) and waste concentration (20, 40, and 60%). The optimum treatment occurred at the time of 15 days and 38.41% of tofu wastewater concentration decreasing up to 76% of COD, 71.78% of BOD, and 75.28% of TSS.

Keywords Phytoremediation · *Vetiveria zizanioides* · Wastewater · Tofu · Zeliac

Introduction

Industrial activity of tofu in Indonesia is mostly domestic industries; most industries do not have a waste treatment facility. Until now, nearly all tofu factories do not perform a good waste management. Tofu wastewater contains organic substances that can cause the rapid growth of microbes in the water. The COD and BOD of wastewater from tofu processing facilities in Banda Aceh were ranging from 5000 to 8500 and from 3500 to 4500 mg/L, respectively. Those high concentrations of organic compounds can cause bad odours, pollution of the surface, ground water, and river (Faisal et al. 2015). This can lead to decrease in oxygen levels. In addition, Tofu wastewater contains suspended substances as well, resulting in turbidity. Some attempts have been conducted to reduce levels of organic matter in the industrial tofu wastewater, such as the use of physical–chemical methods (Saryanaran et al. 2004) and biological aerobic methods (Tay 1990). However, the application of the method is relatively difficult. This is due to the large amount of coagulant required, the operation is relatively complex, high cost of electricity for aeration, high production of sludge or biomass, and requires a large area.

Phytoremediation is a way to remove contaminants using the plant. Selection of appropriate plant is one important factor in implementing phytoremediation. Effendi et al. (2015b) state that phytoremediation has many advantages compared to other techniques because it can be done with minimal environmental disruption. This technique is widely applied in Asia, America, and Europe (Whitney et al. 2003) in dealing with environmental pollution, especially water pollution. Some types of plants that play an important role in waste treatment, are spinach (Effendi et al. 2015d), lettuce (Effendi et al. 2017; Purwandari et al. 2017; Wahyuningsih et al. 2015), and vetiver grass (Danh et al. 2009; Effendi et al. 2015a).

Vetiver grass (*V. zizanioides*) has been utilized for waste treatment activities in the polluted environment. *V. zizanioides* constitutes a quite strong resistance plant and not easy to die and has a heavy fiber and long roots that allow much more uptake of pollutants and provide a convenient condition for aerobic bacteria to develop naturally. Therefore the process of organic substance decomposition presumably lasts more effective than any other plants. Some studies suggest that *V. zizanioides* is used for the processing of organic wastewater from tapioca factory (Indrayatie et al. 2013), study using vetiver plantlets on floating platform with

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aeration to degrade phenol in illegally dumped industrial wastewater (Phenrat et al. 2017), total organic pollution and tetracycline waste (Datta et al. 2013), as well as organic waste with floating wetlands (Chua et al. 2012). In addition, *V. zizanioides* and tilapia have an excellent performance when they are cultivated with aquaponics system (Effendi et al. 2015a). *V. zizanioides* also has a high economic value, such as the unique craft materials (Tripathy et al. 2014), the raw material of cosmetics and perfumes (Bhatia et al. 2008).

Use of the adsorbent is an alternative method of waste treatment. This method is effective and inexpensive. The most widely adsorbent used is a zeolite. Sulfide, phenol, and chromium (VI) derived from landfill leachate and domestic sewage are removed by zeliac, zeolites and activated carbon with the method of sequencing batch reactor (SBR) (Mojiri et al. 2015a). The results show that the addition of zeliac had a higher performance in removing Cr(VI).

Zeliac is a new adsorbent comprising a mixture of zeolite, activated carbon, lime, rice husk ash, and cement. In addition to the removal of heavy metals, zeliac can also eliminate other pollutants in wastewater. Zeliac were used as a filter on the tofu wastewater treatment. This study was aimed to analyze the utilization of *V. zizanioides* as a phytoremediator in the process of tofu wastewater treatment using zeliac.

Materials and methods

The research was conducted at the Laboratory of Environmental Research Center, Bogor Agricultural University, Indonesia. *V. zizanioides* and zeliac were used as a filter on the tofu wastewater treatment. *V. zizanioides* were selected based on the estimation of similar age, a height of 10–15 cm. *V. zizanioides* were stored on the vessel with the size of $30 \times 20 \times 25$ cm^3 and acclimatized for 7 days. One container was composed of 4 clumps, and each clump had net weight of approximately 30 g.

Each container was put into tofu liquid waste; then the treatment was tested in accordance with a predetermined combination of experiments. To maintain the position, Vetiver grass was placed on the pot with rockwool media. Pots with styrofoam holder were placed on the surface of tofu liquid waste. Figure 1 shows the experimental design using vetiver grass and zeliac. Zeliac was only used in the initial stages as a filter. Each container contained 2 kg of zeliac. Subsequently, the vetiver grass was planted for 3, 9 and 15 days. There were 13 treatment combinations of time (3, 9 and 15 days) and waste concentration (20, 40, 60%). While, media maintenance volume was 20 L.

Materials used for the manufacture of zeliac consisted of zeolites, activated carbon, lime, rice husk ash and cement which were milled (pass through a 300 mm sieve mesh). Furthermore, water was added and blended perfectly with the materials. The mixture was poured into a mold, left for 24 h. Subsequently, it was removed from the mold and immersed in water for 3 days. Thereafter, the mixture was allowed to dry for 2 days and will be destroyed by itself (Mojiri et al. 2015b). Quality test of tofu wastewater was carried out on COD, BOD, TSS and turbidity, referring to the APHA (2005).

Specific growth rate (%) was determined by the following equation (Kittiwongwattana and Supachai 2013).

$$\mathrm{SGR} = \left(\frac{\ln X_t - \ln X_0}{t - t_0} \right) \times 100\%$$

where SGR is the specific growth rate (%), X_0 is the initial wet weight at time 0 (g), X_t is the final wet weight at time t, t_0 is the initial time of observation (day), t is the research duration (day).

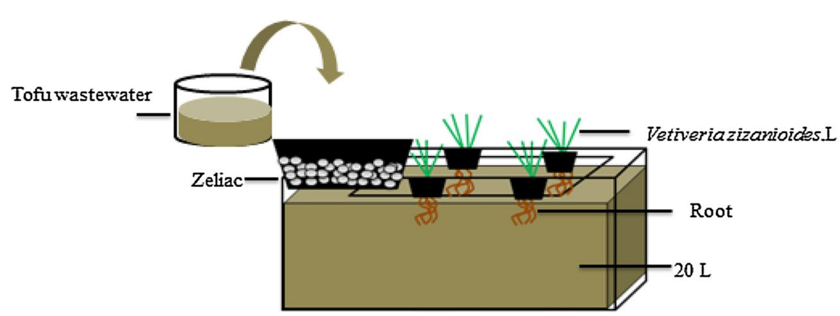
The removal efficiency was calculated by the following formula (Khan et al. 2009):

$$\%\text{removal efficiency} = \frac{a - b}{a} \times 100$$

where a is the initial value of parameter, b is the final values of parameter.

Response surface methodology was applied following central composite design with two factors: the levels of waste (20, 40, 60%) and time (3, 9, 15 days). Before the experiment, a combination of treatment was determined using Design Expert 7.0 software, to obtain as many as 13 experimental designs. Surface response method was a set of mathematical and statistical techniques that are useful for

Fig. 1 System design



analyzing the problems in which some independent variables affect response variable and the ultimate goal is to optimize the response. The design model is as follows:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1,j=2}^{k-l,k} \beta_{i,j}, X_i X_j + \varepsilon$$

where the response is shown by Y; X_i and X_j are the factors; β_0 is an established coefficient; β_i, β_{ij} and β_{ii} display the interaction coefficients (linear, quadratic, and second-order terms, respectively), k is number of analyzed parameters.

Results and discussion

Initial characteristics of tofu wastewater prior to treatment were chemical oxygen demand (COD) (5759 mg/L), biological oxygen demand (BOD) (580 mg/L), total suspended solid (TSS) (552 mg/L), and pH (3.9). This value was above the quality standard of the Government Regulation No. 05 of 2014 on Quality Standard of Industrial tofu wastewater namely BOD (150 mg/L), COD (300 mg/L), TSS (200 mg/L) and pH (6–9). Table 1 shows the removal response of COD, BOD, TSS, and the increase of pH.

Figure 2a is a 3D surface response of COD reduction which shows that the concentration of the waste and time had a significant effect on the reduction of COD. The color difference contained in the chart shows the change in the value of COD reduction response. Removal percentage of COD increased from 22.90% (3 days and 40% waste) to 89.33% (15 days and 40% waste). Meanwhile removal percentage of BOD increased from 16.66% (3 days and 40% waste) to 86.73% (15 days and 40% waste) (Table 1). Dhas (2008) stated that the activated carbon and lime mixture are an alternative treatment to remove COD. In this study, zeliac contained activated carbon, rice husk ash, lime, cement, and zeolite. Such materials could effectively remove COD (Klimiuk and Kulikowska 2006). Zeliac was optimally capable of removing COD (Mojiri et al. 2015b). The ferric chloride in combination with synthetic cationic polymer (Oxyfloc-FL-11) in the ratio of 250:20 mg L(−1) resulted in very good removals of COD, BOD, and SS of 75.4, 79.8, and 96.0%, respectively, with complete removal of odor, color and turbidity of waste manufacture of soya milk and tofu (Saryanaran et al. 2004). The combination of tofu-processing waste and digester sludge can be considered to be one of the most promising forms of organic waste for continuous H_2 fermentative production (Kim and Lee 2010).

Removal percentage of BOD increased from 16.66% (3 days and 20% wastes) to 86.73% at 15 days and 60% wastes (Table 1). Surface response in 3D on BOD analysis is shown in Fig. 2b. High BOD indicates a high content of organic matter (for biologically biodegradable organic matter), requiring a sufficient amount of oxygen to decompose the organic material. If the organic content is too large while the oxygen level is inadequate, then there will be oxygen deficiency so it may not support the life of organisms that require oxygen. Microbial decomposition process is important for wastewater treatment. Microbial decomposition processes in wastewater treatment is indicated by the concentration of BOD. Biodegradable tofu waste can be processed with anaerobic method, yielding biogas and fluid, used as liquid fertilizer or can be mixed with the other biomass, such as vegetable waste, husks, etc. (Faisal et al. 2015).

Removal percentage of TSS sharply will affect an increase in turbidity. Turbidity is caused by suspended and dissolved organic and inorganic materials, as well as inorganic and organic materials in the form of plankton and other microorganisms. It will inhibit the process of penetration of sunlight into the waters and ultimately affect water photosynthesis.

Table 1 Treatment variable and water quality decrease percentage

Run	Time (days)	Waste (%)	COD (%)	BOD (%)	TSS (%)	pH
1	15	60	67.13	52.72	75.71	7.7
2	3	40	22.90	19.38	65.16	6
3	9	60	27.54	32.72	54.28	7.8
4	9	40	52.16	36.73	78.08	7.7
5	9	20	57.06	27.38	38.35	6
6	9	40	48.19	20.40	64.04	7.7
7	9	40	49.39	28.57	46.62	7.8
8	15	20	79.47	61.90	75.68	7.5
9	3	20	30.01	16.66	23.28	6
10	9	40	48.19	28.57	43.82	7.7
11	9	40	53.19	36.73	56.17	7.8
12	15	40	89.33	86.73	82.30	7.5
13	3	60	34.00	26.90	30.47	7

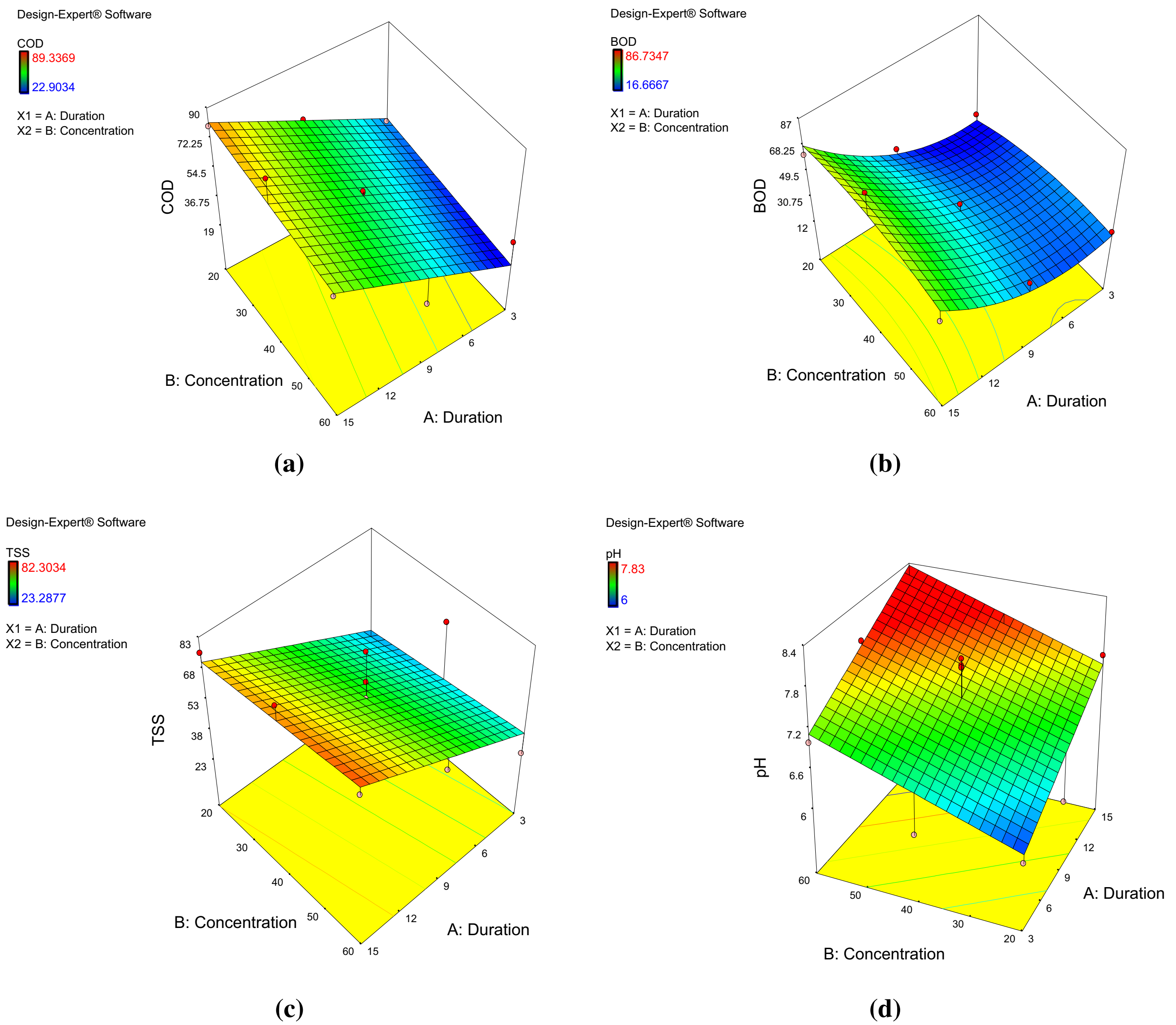


Fig. 2 Plot of 3D surface **a** COD, **b** BOD, **c** TSS, **d** pH

Removal percentage of TSS increased from 23.28% in 3 days and 20% wastes to 82.30% in 15 days and 60% wastes (Table 1). The 3D curve in Fig. 2c shows an increase in TSS. The concentration of waste and time had significant effect on the increase of TSS. The excessive value of TSS will affect the increase of turbidity which further hinders sunlight penetration into the water and ultimately influences photosynthesis of waters (Effendi 2003). Removal percentage of COD, BOD and TSS increased likely because of organic substance decomposition and the process of photosynthesis of plants that produce sufficient oxygen supply for microorganisms, rhizosphere to degrade waste more effectively. The process of photosynthesis in *V. zizanioides* allows the release of oxygen into the air and then diffused into the water around root (*rhizosphere*). The condition of *rhizosphere* zone rich in oxygen causes the development of aerobic bacteria to decompose the organic compounds, thereby decreasing the concentration of COD, BOD and TSS. Some of the organic compounds have been decomposed into other simpler compounds, then absorbed by plants for metabolic processes.

The pH of unprocessed tofu wastewater was 4.45. This value was below the quality standard (6–9), since there were residual acids originating from the manufacturing process in the tofu wastewater. The pH value greatly affects the biochemical process of waters, because the decomposition of organic materials is faster at neutral and alkalis pH (Effendi 2003). According to Boyd (1982), the pH affects the rate of decomposition of organic matter. The pH during the observation ranged 6–7.8.

Table 2 Vetiver root and stem length at the experiment

Run	Root (cm)	Stem (cm)	SGR (%)
1	16.75	27.5	0.024
2	14.75	25.25	0.031
3	15.75	33	0.023
4	15	28.5	0.026
5	15.47	27.25	0.037
6	16.25	32,75	0.020
7	15	28.25	0.023
8	19.25	44.75	0.030
9	14	23.75	0.070
10	16.75	39.75	0.017
11	14.75	37.75	0.025
12	17	41.75	0.027
13	12.25	22.75	0.022

Vetiveria zizanioides root and stem length at the experiment as well as specific growth rate (SGR) is presented in Table 2. Low concentration of waste (20%) related to high specific growth rate (0.30–0.70). However, in general, vetiver could grow in all treatment concentrations. The process of wastewater treatment using aquatic plants occurred by filtration and absorption by the roots and stems of aquatic plants, ion exchange and absorption. Effendi et al. (2015a) stated that the observation of root growth of *V. zizanioides* was potential as a biofilter to absorb organic matter and nutrients (Delis et al. 2015; Effendi et al. 2015a).

The growth of vetiver could be seen from the specific growth rate (SGR) of roots and stems. Vetiver is potential as a biofilter to absorb organic material. Each treatment experienced an increase in the length of roots, stems and specific growth rate (SGR) of *V. zizanioides* (Table 2). The root system grew well with a length of 12.25–19.25 cm. Longer roots will provide an opportunity to absorb nutrients (Effendi et al. 2017). *V. zizanioides* can also grow well. When the plant grows quickly, it needs greater nutrient uptake. The nutrient in the tofu wastewater derived from decomposition of organic material by microorganisms living naturally was absorbed by *V. zizanioides* and served as a source of new tissue formation.

The nutritional requirements are fulfilled from the decomposition of organic materials contained in the water, which will be used by autotrophic organisms, such as aquatic plants and phytoplankton (Effendi et al. 2015c).

Applications for the use of *V. zizanioides* on sewage purification with floating system showed normal growth in a river polluted by domestic waste for 4 weeks (Chunrong et al. 1998). Xuhui et al. (2002) also showed that *V. zizanioides* can survive for 10–12 months in wastewater with COD > 400 mg/L and BOD > 150 mg/L.

Table 3 Response value at optimum condition

Factor		Responses			
A (day)	B (%)	COD (%)	BOD (%)	TSS (%)	pH
15	38.41	76	71.78	75.28	7.8

A time, *B* waste concentration

Table 3 presents the response value at the optimum condition analyzed by Design Expert 7.0 with response surface methodology. Run 12 (15 days, waste 40%) showed highest removal efficiency of COD (89.33%), BOD (86.73%) and TSS (82.30%) in Table 1. However, the removal efficiency of COD (76%), BOD (71.78%) and TSS (75.28%) at the optimum condition obtained by Design Expert 7.0. Maximum is the highest limit, whilst optimum is the most favorable condition under specific sets of comparable circumstances determined by Design Expert 7.0.

Conclusion

The optimum condition of tofu wastewater treatment using vetiver (*V. zizanioides*) and zeliac was 15 days and the waste concentration of 38.41% which could reduce the COD (76%), BOD (71.78%), TSS (75.28%), and an increase in the pH (7.8).

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