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Biodegradability Improvement of Industrial Wastewater Using Hyacinth

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Abstract: This research was to investigate the performance of a low biodegradable wastewater by means of phytotreatment prior to biological oxidation process. Four biodegradability quotients of wastewater were initially ranging from 0.05 and 0.11 and were exposed in simulated collection pond. Weekly performance on biodegradability quotients were shown to decrease linearly without phytointervention, suggesting collected wastewater became biostabilized. However, the hyacinth treatment demonstrated that the quotients were increased exponentially ranging from 3 times of the highest initial quotient and 10 times of the lowest initial quotient. The hyacinth treatment performance on increasing biodegradability were dependent on the initial COD concentration. As a result for the initial COD of less than 500 mg L⁻¹ brought about the increasing rate and the doubling time were about 150% faster rate and 200% shorter period, respectively than those for the initial COD of more than 500 mg L⁻¹.

Key words: BOD/COD ratio, increasing rate, doubling time

INTRODUCTION

Organic matter content of wastewater is measured as the Biological Oxygen Demand (BOD) and the Chemical Oxygen Demand (COD). The extent of degradation by microbes can be evaluated by means of biodegradability quotient measured as BOD/COD ratio. This ratio is commonly used indicator of the degree of biodegradation of the wastewater. A high BOD/COD ratio should be considered sufficient condition to insure biodegradation. As wastewater is degraded, the concentrations of all two measures decrease. Since BOD decreases faster than COD the ratio can approach zero. There is some consensus that stabilized wastewater has a BOD/COD ratio of less than 0.1, a BOD ratio less than 100 mg L⁻¹ and COD less than 1000 mg L⁻¹ (Borglin *et al.*, 2004). However, untreated industrial wastewater has typically a low BOD/COD ratio by which biological process is often ceased. This may indicate the presence either of organic matter that are hard to biodegrade or of toxic substance inhibiting the microbial activities.

The existing industrial wastewater treatment in East Java, Indonesia, typically uses biological oxidation system. The treatment system is equipped with untreated wastewater collection pond. The untreated wastewater has a detention time of about seven days prior to biological oxidation treatment. The organic matter characteristic of untreated wastewater has typically low BOD and high COD, requiring treatment in order to render refractory organics susceptible to biological oxidation.

Increasing biodegradability of a low BOD/COD ratio could be carried out by addition of organic chemicals which have high BOD/COD ratio such as glucose, methanol and acetic acid. Or, mixing the low biodegradable wastewater with high biodegradable wastewater would increase biodegradability of the low BOD/COD ratio. An option of using natural organic chemicals produced by plants which is released from roots would be promising. Plant roots release exudates such as short chain organic acids, phenolics, enzymes and proteins which are highly biodegradable. A mixture of organic matter-containing wastewater with low BOD/COD ratio and organic matter-releasing plant roots with high BOD/COD ratio could be expected to increase biodegradability of untreated wastewater.

To this purpose phytotreatment method would be proposed to achieve results with a simple cost effective system. A floating aquatic plant waterhyacinth (*Eichhornia crassipes*) has a worldwide invasive plant. Hyacinth is capable of rapid reproduction and able to tolerate a wide range of environmental conditions (Toft *et al.*, 2003). Hyacinth has been known to assist in the purification of water and wastewater because of its settlement action and absorption capacity. Hyacinth has been investigated for use in rhizofiltration, phytodegradation and phytoextraction (Salt *et al.*, 1995). In addition hyacinth is readily available in local watercourses and wetlands. Therefore this research was conducted to assign hyacinth as phytosanitary engineer to treat a low BOD/COD ratio of untreated wastewater and

producing high BOD/COD ratio. A potential ability of the hyacinth in improving biodegradability of untreated wastewater will contribute in improving the existing biological oxidation performance.

MATERIALS AND METHODS

This research was conducted in the largest industrial estate in East Java, namely Pasuruan Industrial Estate at Rembang (PIER). The PIER is situated 60 km southeast of Surabaya, the second largest city in Indonesia. The experiment was carried out in a greenhouse during dry season (July to August 2004) and rainy season (February to March 2005). The experiment arrangements were set up to simulate the existing industrial wastewater treatment. The untreated wastewaters were collected randomly from four factories (A, B, C and D) within the PIER property with varying BOD/COD ratio ranging from 0.05 and 0.11. Twenty-four tanks were provided, made of black plastic tanks of working capacity 90 L and each tank had a surface area of 60 sq cm and water depth of 30 cm. Twelve tanks were provided for hyacinth treatment. An amount of 85 L untreated wastewater A, B, C and D was added to each tanks of A, B, C and D, respectively. Additional 5 L nutrient water, which was used to culture hyacinth, was added to each tank to ensure that the availability of nutrients would not be the limiting factor for biotic growth. Selected hyacinth of three propagules were placed in each tank. Another twelve tanks without hyacinth treatment, representing the existing collection pond, were provided with the same arrangements.

Hyacinths were collected from a natural watercourse nearby. They were cleaned and placed in nutrient rich water. The plants were placed in nutrient rich water for a week to encourage growth and to ensure that the plants were healthy before placing them in untreated wastewater. The nutrient rich water consists of Huttner's solution (Caicedo *et al.*, 2000), i.e., 12.2 mg $\text{CaCl}_2 \text{ L}^{-1}$, 50.0 mg EDTA L^{-1} , 40.0 mg $\text{K}_2\text{HPO}_4 \text{ L}^{-1}$, 20.0 mg $\text{NH}_4\text{NO}_3 \text{ L}^{-1}$, 6.5 mg $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O L}^{-1}$, 1.5 mg $\text{H}_3\text{BO}_3 \text{ L}^{-1}$, 2.5 mg $\text{Na}_2\text{MoO}_4 \cdot \text{H}_2\text{O L}^{-1}$, 0.4 mg $\text{CuSO}_4 \cdot 5\text{H}_2\text{O L}^{-1}$, 0.02 mg $\text{CoSO}_4 \cdot 7\text{H}_2\text{O L}^{-1}$, 3.5 mg $\text{MnCl}_2 \cdot 4\text{H}_2\text{O L}^{-1}$, 2.5 mg $\text{FeSO}_4 \cdot 7\text{H}_2\text{O L}^{-1}$ and 50.0 mg $\text{MgSO}_4 \cdot 7\text{H}_2\text{O L}^{-1}$. After a week of incubation, hyacinth propagules were selected. The selected propagules had three leaves and were about 18-20 cm in height and the roots length were about 14-16 cm.

All tanks were operated as weekly renewal feed batch reactors. Wastewater was put stagnant in the tank during seven days and was not treated with aeration and replenishment of wastewater due to evaporation and/or evapotranspiration. The seven days detention time of

wastewater in the collection pond was taken as a reference exposure time for the batch experiment. The tanks size, dimension and time of exposure were sufficient to accomplish the simulated wastewater collection pond (Mangkoedihardjo, 2002). Then replacements of fresh wastewater from the same sources were carried out each week. After one month of exposure, the hyacinths were harvested and replaced with new ones. This experiment was replicated three times simultaneously and run for two months.

Daily observation on temperature, pH and Dissolved Oxygen (DO) were measured by means of electronic probes using Water Quality Checker, TOA WQC-22A. The three parameters were useful to confirm growth conditions during the experiment. Daily observation for evaporation (E) of wastewater in the tanks without hyacinth and evapotranspiration (Et) of wastewater in the tanks of hyacinth treatment were carried out by measuring wastewater depletion using a ruler. Since the surface area of the tank was known then volume of wastewater loss as E and Et could be calculated. The two parameters were useful to take into account soluble and/or volatile BOD and COD losses. Daily measurement of BOD and COD were determined using the dilution method and the dichromate method, respectively. In connection with biodegradation, microbial Colony Forming Units (CFU) were examined weekly by means of general plate count method. The sample collection, handling and analysis of CFU, BOD and COD were carried out in accordance with Standard Methods (1995).

RESULTS AND DISCUSSION

Supporting facts: Result on supporting parameters for simulated wastewater treatment showed that wastewater temperatures for all treatment during exposure were ranging from 23 and 35°C. Measurement of pH levels in all wastewater were shown to decrease from 7.1 ± 0.2 to 6.6 ± 0.1 . DO levels in wastewater without hyacinth were decline from 6.7 ± 0.1 to 5.2 ± 0.1 . Decreasing DO levels from 6.7 ± 0.1 to 4.6 ± 0.1 were observed in wastewater with hyacinth. However, the DO levels were quite high at the range of temperatures even no mechanical aeration was carried out during the experiment. Especially in hyacinth treatment the DO was not suppressed into anaerobic condition probably due to the result of photosynthesis during the day by which a portion of produced oxygen was dissolved in wastewater (Bich *et al.*, 1999; Mangkoedihardjo, 2002). All the hyacinths were healthy and green during the experiment and most of the plants appeared to grow showing new shoots after a week of exposure. Therefore the quality parameters of

temperature, pH and DO were not limiting conditions for biotic growth.

A fluctuation of evaporation was less than evapotranspiration. This was result in high ratio of Et/E which was ranging from 1.6-2.8 (daily) and 2.0-2.1 (weekly). It is shown that the presence of hyacinth would result in higher loss of wastewater than without hyacinth. This characteristic was accounted for significant contribution on COD loss through convective flow of wastewater into the plants, resulting in increasing BOD/COD ratio of the waste.

Microbial colony forming units in the tanks without hyacinth were shown to decline from 7×10^5 – 4×10^6 to 5×10^4 – 4×10^4 CFU/100 mL. However, the presence of hyacinth would increase the microbial population from 2×10^5 – 3×10^6 to 4×10^8 – 4×10^9 CFU/100 mL. The extent of the microbial population change was determined using the following equation:

$$\text{pCFU} = \log \text{CFU} \quad (1)$$

At the beginning and at the end of exposure, for tanks without hyacinth pCFUs were shown to decline from 4.2-3.6 to 2.8-2.4, whereas for tanks of hyacinth treatment were increased from 1.5-2.9 to 4.8-5.4. Therefore microbial colonies in wastewater containing-tanks of hyacinth treatment were shown significant increase. The presence of hyacinth roots were probably brought about increasing CFU that the size and variety of microbial populations were increased in the rhizosphere (Olson and Fletcher, 2000).

In fact the pH(s) were decline ranging from 1 and 2 levels and DO(s) were decline about 2 levels. These suggest that there was a stimulation of microbes by plant root exudates, compounds produced by plants and released from plant roots. Plant exudates include sugars, amino acids, organic acids, fatty acids, sterols, growth factors, nucleotides, flavanones, enzymes and other compounds (Shimp *et al.*, 1993). The exudates can also result in alteration of pH and DO which often creating more favorable environments for microbes, regardless of the production of exudates (Bich *et al.*, 1999; USEPA, 2001).

BOD and COD profiles: Time profiles of BOD and COD for multiple seven days of exposure during two months are presented in Table 1 (wastewater A), Table 2 (wastewater B), Table 3 (wastewater C) and Table 4 (wastewater D). Two categories of initial organic matter representing BOD/COD of less than 0.1 was made. First category was BOD of more than 50 mg L^{-1} and COD of more than 500 mg L^{-1} (wastewater A and B). 1 Second category was BOD of less than 50 mg L^{-1} and COD of less than 500 mg L^{-1}

(wastewater C and D). It is shown that even the organic contents of wastewater initially were varied each week due to replacement, however, the trends of BOD and COD were consistent, i.e. increasing BOD and decreasing COD, suggesting the hyacinth was capable to treat a low biodegradability of wastewater.

It is shown for hyacinth treatment that COD losses were significantly higher than without hyacinth. The tremendous amount of COD losses from wastewater, i.e., 54-78%, might be due to the sequential processes as follows. Firstly, rhizodegradation of COD in the rhizosphere brought about by co-operation of bioactivity between plant roots and microbes. An increase of BOD in the tanks of hyacinth might be due to releasing exudates from plant roots. The presence of exudates could stimulate significantly higher population of microbes in the tanks of hyacinth. This compares favorably with the result obtained by Olson and Fletcher (2000) in their work with ecological recovery of vegetation at a former industrial sludge and Coleman *et al.* (2001) in their work with production of organic carbon due to the presence of roots in association with microbial activity.

The exudates might be used as a carbon source instead of the contaminant and/or degradation of the exudates could stimulate cometabolism of contaminants in the rhizosphere. Organic contaminants in wastewater could be broken down into daughter products or completely mineralized to inorganic products such as carbon dioxide and water by microbes. The current research identified an increase of BOD due to the presence of hyacinth and increasing of CFU that brought about COD losses. However, quantitative correlation between BOD and CFU was beyond the scope to the objective. Therefore further investigation is needed to assess the extent of increasing BOD and CFU that result in COD losses.

Secondly, a soluble COD might be able to pass through the protective barrier of the rhizosphere with the subsequent transformation processes occurring within the plant (phytodegradation). Plants transform organic contaminants through various internal, metabolic processes that help catalyze degradation. The contaminants are degraded in the plant with the breakdown products subsequently stored in the vacuole or incorporated into the plant tissues (ITRC, 2001). In fact the hyacinths were healthy and shown new shoots during the experiment, indicating that the possibility of phytodegradation did not affect the plant life. It was interesting to note that COD losses from wastewater ranging from 300 and 400 mg L^{-1} were subject to phytodegradation without toxic effect to hyacinth.

Thirdly, considering the wastewater-plant-atmosphere chain mechanisms, the soluble COD, or a

Table 1: Time profile of BOD and COD for wastewater A

		Without hyacinth							Hyacinth treatment						
		Days							Days						
mg L ⁻¹	Weeks	1	2	3	4	5	6	7	1	2	3	4	5	6	7
BOD	1	89.8	89.3	87.5	85.9	86.2	85.7	84.2	89.8	80.2	84.9	89.2	95.1	108.3	113.2
COD	1	826.1	826.1	822.3	818.9	818.8	818.4	817.6	826.1	751.7	698.9	548.4	447.8	406.9	379.2
BOD	2	91.2	89.3	88.1	86.8	86.0	85.9	85.2	91.2	87.8	86.5	90.2	94.0	110.2	124.0
COD	2	823.8	823.9	822.5	819.0	818.2	818.0	817.4	823.8	803.2	788.3	556.7	448.4	405.6	390.1
BOD	3	89.9	90.0	88.2	87.7	86.9	86.9	85.9	89.9	86.5	85.2	90.0	96.0	110.7	118.9
COD	3	842.3	839.2	837.8	834.7	832.7	830.1	829.4	842.3	818.9	699.1	550.8	449.8	405.0	399.1
BOD	4	93.7	92.2	90.2	89.2	88.2	87.9	86.1	93.7	89.2	86.1	88.3	96.7	111.7	115.9
COD	4	847.2	845.9	844.1	843.3	842.1	841.1	840.0	847.2	829.9	699.0	543.9	454.7	443.8	418.0
BOD	5	96.8	92.9	91.8	89.2	88.7	86.6	84.1	96.8	94.7	97.2	101.6	126.9	132.8	144.2
COD	5	872.2	869.2	858.7	856.4	838.6	828.2	819.8	872.2	872.2	789.2	608.4	597.3	488.3	478.3
BOD	6	97.1	93.8	92.8	90.8	89.6	87.5	85.0	97.1	96.1	90.3	94.7	103.1	117.2	125.4
COD	6	883.2	879.2	874.4	869.3	858.3	819.8	817.9	883.2	883.2	758.1	603.1	488.3	468.5	451.3
BOD	7	99.4	98.9	97.3	96.6	94.9	92.0	89.6	99.4	99.4	104.7	116.8	124.6	138.7	145.8
COD	7	974.3	933.8	931.8	928.3	913.3	889.6	879.5	974.3	974.2	919.2	696.4	587.5	498.9	474.9
BOD	8	96.4	94.5	91.4	89.4	87.1	86.2	84.1	96.4	94.4	99.2	109.0	117.3	127.3	142.0
COD	8	856.8	848.6	844.0	841.1	829.4	821.2	819.0	856.8	856.8	838.2	686.3	552.0	481.2	466.4

Table 2: Time profile of BOD and COD for wastewater B

		Without hyacinth							Hyacinth treatment						
		Days							Days						
mg L ⁻¹	Weeks	1	2	3	4	5	6	7	1	2	3	4	5	6	7
BOD	1	59.2	60.3	58.9	57.4	56.8	55.7	54.5	59.2	60.8	59.2	56.8	58.3	67.3	71.4
COD	1	611.1	610.2	609.4	607.2	607.1	607.0	606.9	611.1	504.3	338.7	329.9	279.2	242.8	218.7
BOD	2	61.3	62.9	60.9	58.8	57.0	55.7	54.2	61.3	67.9	89.6	82.7	93.0	109.4	121.9
COD	2	614.8	611.3	611.1	610.4	605.8	604.5	601.3	614.8	611.6	489.0	488.0	453.2	401.7	368.4
BOD	3	59.4	60.4	59.1	57.2	57.0	55.0	54.3	59.4	64.0	76.3	73.4	96.3	108.9	116.8
COD	3	623.4	621.5	620.6	619.3	609.1	607.7	605.3	623.4	521.7	472.9	462.2	451.0	393.3	361.7
BOD	4	59.9	60.7	59.3	58.2	57.9	56.9	56.1	59.9	65.8	85.7	82.8	99.9	116.7	129.8
COD	4	626.2	625.6	624.7	623.9	621.7	614.7	612.4	626.2	507.9	479.3	438.9	407.3	413.8	394.7
BOD	5	89.7	90.0	87.2	84.0	80.8	74.8	72.4	89.7	94.8	110.7	99.2	128.7	131.0	134.7
COD	5	897.3	886.3	876.6	875.6	848.4	821.8	818.4	897.3	789.0	639.1	618.6	596.3	467.3	416.4
BOD	6	87.7	87.6	85.8	83.4	80.4	77.4	75.2	87.7	99.0	108.9	108.8	123.1	127.2	130.3
COD	6	907.2	898.3	873.6	872.0	859.1	827.9	818.7	907.2	813.2	634.8	623.3	538.3	461.4	401.2
BOD	7	88.4	87.7	83.7	81.0	79.6	78.2	74.0	88.4	102.2	115.7	113.7	128.7	133.7	143.6
COD	7	952.7	938.8	932.8	931.8	908.3	869.6	857.9	952.7	854.2	631.5	629.2	589.3	479.7	424.8
BOD	8	89.3	89.8	86.5	83.5	81.7	78.6	74.2	89.3	98.4	109.9	108.6	120.3	127.0	132.4
COD	8	898.6	879.5	844.2	843.2	828.3	822.1	811.2	898.6	817.7	638.1	634.2	572.0	463.3	413.9

modified form of the contaminant within the plant, is translocated up into the leaves. The translocated COD in leaves was volatilized and released to the atmosphere through the process of transpiration (phytovolatilization). This was supported by Et/E ratio of about 2 that characterized the capacity of hyacinth to uptake soluble COD through transpiration mechanism.

BOD/COD ratio: Results of calculated BOD/COD were based on the time profiles for BOD and COD (Table 1-4). The significant finding was the presence of hyacinth brought about increasing of BOD and decreasing of COD. This general principle was arrived to the main objective of this research, i.e., hyacinths were able to increase BOD/COD ratio of wastewater. This means that the hyacinth treatment produces biodegradable wastewater. As a result, subsequent microbial treatment would be appropriate to stabilize the wastewater.

Exponential rate of BOD/COD increase was observed. It was calculated that for the initial COD level of more than 500 mg L⁻¹ that the BOD/COD ratios were shown to increase about 0.2 day⁻¹, whereas they were faster for the initial COD level of less than 500 mg L⁻¹, i.e., 0.3 day⁻¹. Because of different rates of BOD/COD increase due to different initial COD level, therefore it is important to develop a method which can distinguish the specific characteristic of organic matter. The doubling time of BOD/COD ratio for hyacinth treatment was introduced as a means for comparison of organic matter characteristics. This was also as an approach to determine the detention time of hyacinth ponds to treat wastewater and/or time of remediation of polluted environment in general. The doubling time (DT) was defined here as BOD/COD ratio at a certain time would be twice of the initial BOD/COD ratio.

An estimate of the DT was determined by the exponential trendline obtained from the time profiles of

Table 3: Time profile of BOD and COD for wastewater C

		Without hyacinth							Hyacinth treatment						
		Days							Days						
mg L ⁻¹	Weeks	1	2	3	4	5	6	7	1	2	3	4	5	6	7
BOD	1	27.2	26.5	26.4	26.0	25.3	25.4	25.1	27.2	26.7	25.0	27.6	32.5	38.6	42.4
COD	1	348.5	348.4	347.7	347.5	347.1	346.9	346.5	348.5	263.3	156.1	101.4	93.7	89.1	81.5
BOD	2	22.9	22.9	22.0	20.8	19.0	18.7	18.2	22.9	27.7	29.6	32.4	34.2	39.2	41.7
COD	2	344.8	341.3	331.1	326.3	320.8	314.5	299.4	344.8	311.5	209.7	113.8	101.5	81.8	78.3
BOD	3	29.4	28.4	28.1	27.2	26.0	25.0	24.8	29.4	35.8	38.3	46.8	56.1	58.3	59.2
COD	3	353.4	351.5	350.5	349.4	339.1	327.3	319.3	353.4	321.3	221.2	178.0	160.4	153.4	121.4
BOD	4	29.9	28.4	28.2	27.2	26.9	25.7	25.1	29.9	31.6	36.2	48.7	55.3	57.9	59.0
COD	4	358.2	355.3	351.9	333.9	331.3	314.4	305.4	358.2	309.6	219.1	182.8	157.2	132.5	108.8
BOD	5	38.1	36.0	35.2	33.8	30.3	29.7	29.4	38.1	39.8	43.0	45.2	49.5	52.0	60.7
COD	5	487.9	486.1	481.0	459.5	423.3	408.9	402.3	487.9	384.8	249.5	161.0	142.1	123.3	114.3
BOD	6	37.7	36.7	35.7	33.5	30.3	28.4	27.9	37.7	39.8	43.2	48.7	53.9	60.2	64.3
COD	6	479.2	474.3	472.2	448.1	422.7	402.7	389.3	479.2	386.3	282.4	183.3	157.3	133.2	121.3
BOD	7	36.3	35.8	35.0	33.8	32.5	31.2	30.9	36.3	39.3	42.4	48.2	54.9	58.1	62.3
COD	7	458.8	456.7	453.4	451.3	432.1	419.2	417.9	458.8	392.7	271.6	180.2	159.4	132.4	118.2
BOD	8	37.3	36.2	35.6	33.9	32.0	30.3	29.1	37.3	39.2	44.2	48.4	56.3	60.1	63.5
COD	8	486.9	478.5	448.7	443.9	440.4	417.3	403.7	486.9	397.7	276.4	176.4	161.2	143.7	129.4

Table 4: Time profile of BOD and COD for wastewater D

		Without hyacinth							Hyacinth treatment						
		Days							Days						
mg L ⁻¹	Weeks	1	2	3	4	5	6	7	1	2	3	4	5	6	7
BOD	1	22.4	23.5	22.1	21.2	20.8	19.7	19.2	22.4	21.6	20.5	24.2	28.0	31.3	33.1
COD	1	468.9	467.6	466.9	465.4	464.8	464.3	463.7	468.9	334.8	294.2	239.8	207.8	133.7	101.4
BOD	2	21.4	22.0	21.8	20.8	19.2	18.7	16.2	21.4	29.7	31.8	34.9	38.7	43.9	46.7
COD	2	464.7	444.1	443.8	440.4	429.0	426.4	426.3	464.7	461.1	454.8	334.9	293.8	191.1	148.8
BOD	3	23.6	22.2	21.2	20.6	19.9	18.1	17.8	23.6	25.8	27.4	31.7	37.7	43.9	47.0
COD	3	486.7	453.7	452.2	450.9	446.2	439.9	439.8	486.7	423.5	399.2	303.3	267.7	193.4	147.2
BOD	4	23.4	22.9	20.8	20.3	19.4	18.9	18.0	23.4	27.2	29.3	32.5	34.5	38.0	39.7
COD	4	471.9	454.3	453.9	452.9	442.4	414.8	414.3	471.9	419.8	421.2	342.8	267.1	155.4	115.3
BOD	5	20.2	19.9	18.3	18.4	17.9	17.3	16.4	20.2	25.0	26.8	35.3	38.9	45.9	48.4
COD	5	427.9	411.3	410.8	409.4	403.2	402.8	400.0	427.9	403.7	389.4	340.8	300.0	187.3	148.2
BOD	6	21.4	21.0	20.1	19.4	19.1	18.1	17.2	21.4	27.8	30.2	38.9	43.7	50.3	55.3
COD	6	435.9	417.6	416.2	415.4	414.5	413.3	411.3	435.9	428.5	419.2	373.5	303.3	213.9	166.8
BOD	7	22.1	22.0	20.4	19.8	19.4	18.2	17.2	22.1	29.8	31.5	37.2	42.7	46.9	53.5
COD	7	442.3	436.3	433.3	432.3	431.2	429.3	426.9	442.3	438.9	431.8	383.7	313.7	203.4	167.3
BOD	8	20.5	21.1	20.3	19.3	19.0	18.0	17.1	20.5	26.2	28.7	34.6	39.6	45.4	52.0
COD	8	431.7	411.2	410.1	409.1	408.9	407.9	405.7	431.7	417.7	427.8	353.5	311.2	199.7	159.5

BOD/COD ratio. Accordingly the DT was determined using the following equation:

$$DT = 0.69/k \quad (2)$$

Where k is increasing rate constant (day⁻¹). It was calculated that DT for the initial COD level of more than 500 mg L⁻¹ was about 4 days and for the initial COD level of less than 500 mg L⁻¹ was about 2 days. The DTs were shorter than the existing detention time of untreated wastewater collection pond (7 days).

Stabilization of wastewaters in the existing collection pond, represented as without hyacinth, were linearly decline at a rate of 0.001 day⁻¹. This compares favourably with the values obtained from the work with the stabilization rate of leachate biotreatment and the work with the COD removal of industrial wastewaters (Borglin *et al.*, 2004; Guan *et al.*, 2004;

Krzystek *et al.*, 2003). The low stabilization rate suggests that the existing collection pond as such has no effect on changing biodegradability of wastewater for seven days. In addition the fact that CFUs were declined, suggesting the COD partially contained toxic materials towards microbes.

In fact the initial COD of more than 500 mg L⁻¹ could be reduced by means of phytotreatment. This suggests the treated wastewater will be more biodegradable than wastewater without phytotreatment. It is proposed that a low BOD/COD ratio of 0.1 as an indicator for the biostabilized wastewater would be verified for BOD of less than 100 mg L⁻¹ and COD of less than 500 mg L⁻¹. To do so further research on COD of more than 500 mg L⁻¹ and BOD of less than 100 mg L⁻¹ for industrial wastewater is necessary whether it is an organic biotoxicity indicator for BOD/COD of less than 0.1.

In connection with the existing wastewater treatment system, it is expected to be appropriate for conversion of the existing collection pond into two compartments, i.e., a series of collection pond and hyacinth pond. The collection pond occupied for detention time of three days (BOD/COD ratio ranging from 0.15 and 0.18 was achieved due to mixing with various wastewaters) and followed by hyacinth pond with detention time of four days (brought about increasing BOD/COD ratio of more than 0.30, this research). This will decrease organic loading of biological oxidation process, supporting the unit performance works properly. The co-processes of phytotreatment and biotreatment will be promising system to produce final effluent quality which will be safer than without hyacinth treatment.

CONCLUSIONS

Phytocapacity as demonstrated by hyacinth determined significantly high COD losses from wastewater and BOD enrichment of wastewater resulting in increasing BOD/COD ratio of wastewater. Initial COD concentration in wastewater would result in significant difference of organic matter performance parameters. For the initial COD of more than 500 mg L⁻¹, BOD/COD ratios were shown to increase about 0.30, increasing rates were about 0.2 day⁻¹ and DTs were 4 days. For the initial COD of less than 500 mg L⁻¹, BOD/COD ratios were shown to increase 0.33-0.52, increasing rates were about 0.32 day⁻¹ and DTs were 2 days. Finally, the increasing amount of BOD, microbial population and evapotranspiration in hyacinth treatment suggest that enhanced rhizodegradation, phytotransformation and phytovolatilization did occur.

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