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Denitrification of Secondary Wastewater Using Sawdust

by

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Abstract

This contribution is devoted to the use of sawdust as materials to improve the efficiency of removing nitrate from the secondary wastewater.

Sawdust, a relatively abundant and inexpensive material is being investigated as a porous treatment media to enhance removal of contaminants from wastewater. Successful nitrate removal from secondary wastewater has been demonstrated in a laboratory experiment using columns filled with porous soil material and sawdust and/or bamboo chip served as an organic carbon source. While the availability of organic carbon is one of the most important factors that affects denitrifying activity in soil.

A mathematical solute transport model was developed to predict the nitrate degradation processes through a natural filter. The model computes changes in concentration over time caused by the processes of advection, dispersion and biological reactions. Results from a laboratory soil-sawdust and soil-bamboo chip columns experiments were used to verify the simulation results of the model.

This study demonstrated that denitrification using sawdust as a carbon source can effectively remove nitrate from secondary wastewater when the carbon source is limiting in the influent secondary wastewater or groundwater.

Keywords: Denitrification, Denitrification using sawdust, Organic carbon source, Nitrate, Bacteria growth

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1. Introduction

Recycled water has become one of the significant resources used to replenish the existing water bodies, especially in the areas where the water resources are not sufficient to meet the demand of growing population.

The problem of removing pollutants from water and wastewater has grown with rapid industrialization. Heavy metals, dyes, oil and other substances, which are toxic to many organisms, are present in wastewater streams from many industries. Recently environmental concerns are increasing. Wastewater generated in large volumes with high pollutant load must be cleaned before it is released or reused. Many methods can be used to remove unwanted materials from water and wastewater as for example membrane filtration, coagulation, adsorption, oxidation, ion exchange and precipitation, etc. these methods have limitation due to high cost, low efficiency, or inapplicability to certain pollutants.

A nitrogen-containing compound released into environment creates serious problems, such as deterioration of water quality and potential hazard to human health, because nitrate in the gastrointestinal tract can be reduced to nitrite ions. In addition, nitrate and nitrite have the potential to form N-nitrous compounds, which are potent carcinogens.

Biological removal of nitrate is widely used in the treatment of domestic and complex industrial wastewaters [1), 4), 7), 8)]. Biological denitrification enables transformation of oxidized nitrogen compounds by a wide spectrum of heterotrophic bacteria into harmless nitrogen gas with the accompanying carbon removal. Biological denitrification, among various denitrification methods, is very attractive because of its economical and environmental advantages. However, carbon source feeding is required to maintain biological activity in biological denitrification.

The need for development of effective and economical methods for removal of unwanted substances from wastewater results in a research for unconventional treatment methods and new materials.

Many agricultural byproducts have little or no economic value, and some, such as sawdust, which are available in large quantities in lumber mills, represent a disposal problem. The use of sawdust for removing pollutants would benefit both the environment and wood agriculture. Contaminated waters would be cleaned, and a new market would be opened for the sawdust.

Sawdust can be used for the removal of toxic salts from water, for example, denitrification walls amended with sawdust have proved effective in nitrate removal [1)]. The denitrification wall was constructed by digging a trench that intercepted groundwater. The excavated soil was mixed with sawdust 30% as a carbon source then returned to the trench. Nitrogen levels in the wall and in the surrounding groundwater were monitored for one year. The denitrification wall successfully removed nitrates from water but did not provide long-term removal. Effectiveness of the wall depended on nitrate concentration not on the amount of carbon in the sawdust. Throughout the year, the wall proved to be very efficient even with the decrease in sawdust availability. This technique proved to be very useful in nitrate removal from groundwater.

Sawdust material has proven to be a promising material for removal of contaminants from wastewater. Not only is sawdust abundant, but also it is really an efficient and economic adsorbent that is effective to many types of pollutants, such as, dyes, oil, salts, heavy metals, etc [2)].

Numerical flow and reactive transport model can be helpful tools in the designing and monitoring of denitrification filters and in predicting long-term effects of denitrification processes on nitrate contaminant transport. In this study, a numerical model capable of simulating the processes involved in biological denitrification was developed. It is a general model, which provides flexibility in input parameters and configurations. It includes the processes of one-dimensional solute transport and Monod kinetic models. Sawdust and bamboo chip are used as a carbon source to enhance microbial denitrification.

The main objectives of this study were to: (i) investigate the processes of nitrate removal from secondary wastewater by using biological denitrification, (ii) develop a mathematical solute-transport model to predict the nitrate degradation processes through the natural filter enhanced by sawdust, and (iii) evaluate and calibrate the mathematical model using the laboratory soil-sawdust and soil-bamboo chip column experiments.

2. Theoretical Development

2.1 Model processes

The model used in this study is based on the reactive solute transport and biological process. It describes the interaction of O_2, NO_3^-, CH_2O concentration and bacteria growth. This model takes into account three different phases: mobile pore water phase, immobile bio phase and matrix phase, the bio phase is assumed to include all bacteria growth and biological processes.

Figure 1 shows the chemical species considered in the model and mass transfer processes between different phases. This model takes into consideration the mass transfer between different phases (i) Mass transfer between mobile phase and bio phase. (ii) Mass transfer between mobile phase and matrix phase. (iii) Mass transfer between bio phase and matrix phase.

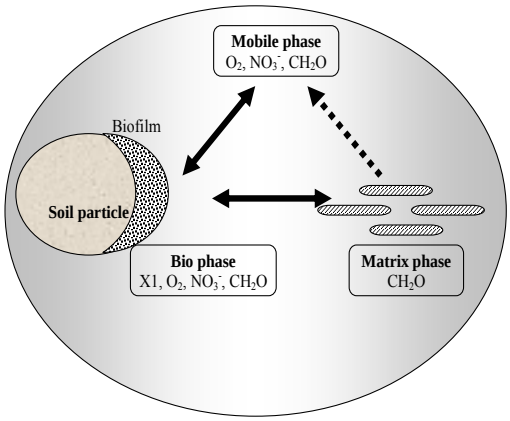

Fig. 1 Chemical species considered in the model and mass transfer processes between different phases.

2.2 Reactive-solute transport

The fundamental one-dimensional partial differential equation governing the advective-dispersive solute transport of contaminants can be written as [3]:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial y}\left(D_L \frac{\partial C}{\partial y} \right) - v' \frac{\partial C}{\partial y} + S_i \tag{1}$$

where C is the volume-averaged concentration, D_L is the longitudinal dispersion coefficient, v' is the average pore velocity, t is the time, y is the distance, S_i is the chemical source-sinks term representing the exchange processes and formulated as [4]:

$$S_1 = \alpha\left(C_{bio} - C_{mob}\right) \tag{2}$$

$$S_2 = \beta\left(C_{mat} - C_{mob}\right) \tag{3}$$

$$S_3 = \gamma\left(C_{bio} - C_{mat}\right) \tag{4}$$

where S_1 is the exchange rate at the concentration difference between the mobile and the bio phase, S_2 is the exchange rate at the concentration difference between the mobile and the matrix phase, S_3 , is the exchange rate at the concentration difference between the bio and the matrix phase, C_{mob} is the concentration of solute in the mobile phase, C_{bio} is the concentration of solute in the bio phase. C_{mat} is the concentration of solute in the matrix phase, α is the mass transfer coefficient between the mobile and bio phases, β is the mass transfer coefficient between the mobile and matrix phases, γ is the mass transfer coefficient between the bio and matrix phases.

The longitudinal dispersion coefficient D_L is described by

$$D_L = \alpha_L v' + D_M \tag{5}$$

where D_L is the longitudinal dispersion coefficient, α_L is the longitudinal dispersivity, and D_M is the molecular diffusion coefficient.

2.3 Bacteria growth

The bacteria can utilize several substrates simultaneously. Bacteria growth is often controlled by availability of substrates. The specific growth rate is assumed to be a function of the concentration of the growth rate limiting substrates.

As described by the ecological redox sequence, nitrate is the first compound to be reduced after oxygen depletion.

Oxygen and nitrate reduction are described by the following reactions:

Oxygen reaction

$$CH_2O + O_2 \rightarrow HCO_3^- + H^+$$

Nitrate reaction

$$5CH_2O + 4NO_3^- \rightarrow 5HCO_3^- + H^+ + 2N_2 + 2H_2O$$

The growth of bacteria is described by Double Monod kinetic equation and it can be written as follows;

$$\frac{\partial X}{\partial t} = v_{\max} \frac{C_1}{K_{s1} + C_1} \cdot \frac{C_2}{K_{s2} + C_2} X \tag{6}$$

where $v_{\max}$ is the maximum growth rate, C_1 is the primary substrate concentration, C_2 is the secondary substrate concentration, K_{s1} is the primary substrate half-saturation constant, K_{s2} is the secondary substrate half-saturation constant, and X is the bacteria concentration.

The decay of bacteria equation can be written as follows;

$$\frac{\partial X}{\partial t} = -v_{dec} X \tag{7}$$

where v_{dec} is the bacteria decay rate.

The model extended to include the switching between aerobic and denitrifying growth conditions is based on the assumption that the same microorganisms are capable of either aerobic or denitrifying growth, depending on the oxygen concentration in their nearby environment and can be written as [5]:

$$F\left(\left[O_2\right]_{bio}\right) = 0.5 - \frac{1}{\pi}\tan^{-1}\left\{\left(\left[O_2\right]_{bio} - \left[O_2\right]_{thres}\right) \times f_{s1}\right\} \tag{8}$$

where $F\left(\left[O_2\right]_{bio}\right)$, is the switching function, $\left[O_2\right]_{bio}$ is the concentration of oxygen O_2 in the bio phase, $\left[O_2\right]_{thres}$ is the threshold concentration of oxygen O_2, and f_{s1} is the slope of switch function.

2.4 Model equations

The chemical species considered in the model are oxygen, nitrate, and organic carbon besides the growth of bacteria; this model takes into consideration the concentration changes of the species in different phases. (i) The concentration change in mobile phase is results of advection, dispersion, mass transfer between mobile phase and bio phases, and mass transfer between the mobile and matrix phases. (ii) The concentration change in bio phase is result of reduction reaction by the bacteria growth, mass transfer between mobile and bio phases, and mass transfer between bio and matrix phases. (iii) The concentration change in matrix phase is result of mass transfer between the bio and matrix phases, and mass transfer between the mobile and matrix phases.

Based on the model processes, reactive-solute transport, and bacteria growth the model equations can be written as listed in **Table 1.**

Table 1 Model equations list for mobile, bio, and matrix phases and bacteria growth.

Mobile pore water phase

$$O_2 : \frac{d[O_2]_{mob}}{dt} = \frac{\partial [O_2]_{mob}}{\partial t} + v' \frac{\partial [O_2]_{mob}}{\partial y} = \frac{1}{\theta_w} \frac{\partial}{\partial y} (\theta_w D_L \frac{\partial [O_2]_{mob}}{\partial y}) + \alpha([O_2]_{bio} - [O_2]_{mob})$$

$$NO_3^- : \frac{d[NO_3^-]_{mob}}{dt} = \frac{\partial [NO_3^-]_{mob}}{\partial t} + v' \frac{\partial [NO_3^-]_{mob}}{\partial y} = \frac{1}{\theta_w} \frac{\partial}{\partial y} (\theta_w D_L \frac{\partial [NO_3^-]_{mob}}{\partial y})$$
$$+ \alpha([NO_3^-]_{bio} - [NO_3^-]_{mob})$$

$$CH_2O : \frac{d[CH_2O]_{mob}}{dt} = \frac{\partial [CH_2O]_{mob}}{\partial t} + v' \frac{\partial [CH_2O]_{mob}}{\partial y} = \frac{1}{\theta_w} \frac{\partial}{\partial y} (\theta_w D_L \frac{\partial [CH_2O]_{mob}}{\partial y})$$
$$+ \alpha([CH_2O]_{bio} - [CH_2O]_{mob}) + \beta([CH_2O]_{mat} - [CH_2O]_{mob})$$

Immobile bio phase

$$O_2 : \frac{\partial}{\partial t} (\theta_{bio} [O_2]_{bio}) = -\frac{1}{U_{O_2}} \left[\frac{\partial \theta_{bio} X}{\partial t} \right]_{aerobic\_condition} - \alpha([O_2]_{bio} - [O_2]_{mob})$$

$$NO_3^- : \frac{\partial}{\partial t} (\theta_{bio} [NO_3^-]_{bio}) = -\frac{1}{U_{NO_3^-}} \left[\frac{\partial \theta_{bio} X}{\partial t} \right]_{denitrifying\_condition} - \alpha([NO_3^-]_{bio} - [NO_3^-]_{mob})$$

$$CH_2O : \frac{\partial}{\partial t} (\theta_{bio} [CH_2O]_{bio}) = -\frac{1}{Y_{CH_2O}^{O_2}} \left[\frac{\partial \theta_{bio} X}{\partial t} \right]_{aerobic\_condition} - \frac{1}{Y_{CH_2O}^{NO_3^-}} \left[\frac{\partial \theta_{bio} X}{\partial t} \right]_{denitrifying\_condition}$$
$$- f_{use} \left[\frac{\partial \theta_{bio} X}{\partial t} \right]_{decay} - \alpha([CH_2O]_{bio} - [CH_2O]_{mob}) - \gamma([CH_2O]_{bio} - [CH_2O]_{mat})$$

Matrix phase

$$CH_2O : \frac{\partial}{\partial t} (\theta_{mat} [CH_2O]_{mat}) = \gamma([CH_2O]_{bio} - [CH_2O]_{mat}) - \beta([CH_2O]_{mat} - [CH_2O]_{mob})$$

Bacteria growth

$$X : \left[\frac{\partial X}{\partial t} \right]_{Total\_Growth} = \left[\frac{\partial X}{\partial t} \right]_{aerobic\_condition} + \left[\frac{\partial X}{\partial t} \right]_{denitrifying\_condition} + \left[\frac{\partial X}{\partial t} \right]_{decay}$$

$$\left[\frac{\partial X}{\partial t} \right]_{aerobic\_condition} = v_{\max}^{O_2} \cdot \{1 - F(O_{2bio})\} \cdot \frac{[CH_2O]_{bio}}{K_{CH_2O} + [CH_2O]_{bio}} \cdot \frac{[O_2]_{bio}}{K_{O_2} + [O_2]_{bio}} \cdot X$$

$$\left[\frac{\partial X}{\partial t} \right]_{denitrifying\_condition} = v_{\max}^{NO_3^-} \cdot \{F(O_{2bio})\} \cdot \frac{[CH_2O]_{bio}}{K_{CH_2O} + [CH_2O]_{bio}} \cdot \frac{[NO_3^-]_{bio}}{K_{NO_3^-} + [NO_3^-]_{bio}} \cdot X$$

$$\left[\frac{\partial X}{\partial t} \right]_{decay} = -v_{X1dec} \cdot X$$

3. Materials and Methods

3.1 Materials

The secondary wastewater effluent was collected from the Wajiro wastewater treatment plant in Fukuoka, Japan and used as the influent in the experiment. **Table 2** shows the concentration of injected wastewater.

Soil, sawdust and bamboo chip used in this study were collected from Fukuoka, Japan. The chemical components of the raw material are given in **Table 4**.

Table 2 Concentration of injected wastewater.

Chemical species	Inject water (mg/L)	Chemical species	Inject water (mg/L)	Chemical species	Inject water (mg/L)
Na	95.2	Fe^{2+}	0.13	NO_3-N	10.5
K	14.5	Mn^{2+}	0.137	SO_4	40
Ca	40.3	TOC	5.6	PO_4-P	0.172
Mg	9.2	Cl	151		

3.2 Column experiment

The column experiment was carried out using glass columns of 45 cm height and 10 cm internal diameter. The wire mesh and filter paper were placed at the bottom of each column as shown in **Fig. 2**. The head and the bottom of column are closed using glass plates with tube insert for the influent and effluents collection respectively. Sampling points were placed at following depths 0, 5, 10, 20, and 30 cm

The columns were packed to height of 30 cm with different mixtures of soil, sawdust and bamboo chip as shown in **Table 3**. The secondary wastewater was constantly supplied at the top of the four columns for the duration of 56 days and average temperature was measured at 22^0C.

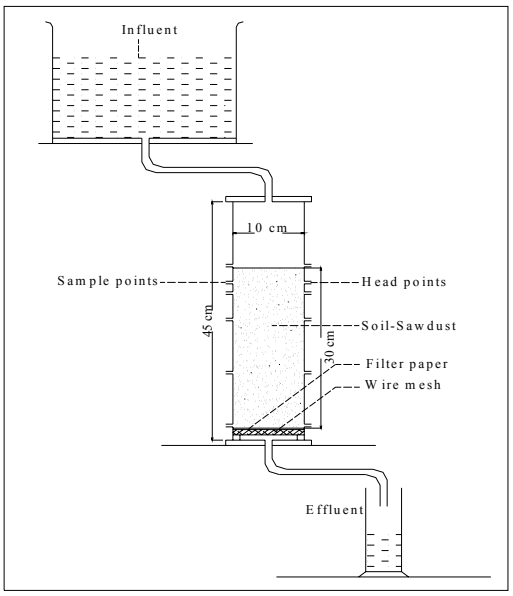

Fig. 2 Schematic of laboratory column experimental.

Table 3 Percentage of materials used in columns.

Material	Column 1	Column 2	Column 3	Column 4
Soil	100%	70%	30%	50%
Sawdust	0%	0%	0%	50%
Bamboo	0%	30%	70%	0%

Table 4 Chemical components of soil, sawdust and bamboo chip.

Materials	Chemical species	Units	Content	TOC (mg/L)
Soil	Fe_2O_3	%	7.5	5.9
	MnO_2	%	0.16	
	Al_2O_3	%	16.1	
	SiO_2	%	43.7	
	Ig-loss	%	5.9	
	C	%	1.57	
	H	%	0.58	
	N	%	0.14	
Sawdust	pH (H_2O)	-	5.1 (20.1)	468
	T-P	mg/kg	40	
	K	mg/kg	478	
	NH_4	mg/kg	7.1	
	C/N	-	259	
	T-C	%	44.1	
	T-N	%	0.17	
Bamboo chip	pH (H_2O)	-	7.6 (20.1)	1570
	T-P	mg/kg	2340	
	K	mg/kg	21700	
	NH_4	mg/kg	59	
	C/N	-	23.1	
	T-C	%	36.2	
	T-N	%	1.57	

3.3 Numerical simulation

In this study the finite difference method and method of characteristics schemes have been used as numerical solution technique to solve the model equations [6].

The general procedures performed in advection-dispersion-reaction model for a typical simulation run are illustrated in **Fig. 3**.

The model of denitrification is very complex because it involves many parameters. Monod kinetic, stoichiometric and switching function parameters for the denitrification model were taken from several studies related to wastewater treatment modeling and simulation of denitrification [7), 8), 9), 10)]. Some parameters were adjusted to obtain the best fit of the model to the experimental data. The values of the stoichiometric, kinetic, switching function and denitrification parameters are listed in **Table 5.**

The initial and boundary conditions were selected depending on the experimental set-up, injection wastewater analysis and chemical components of raw materials.

The initial and boundary conditions are given in **Table 6** and calculation conditions are given in **Table 7**.

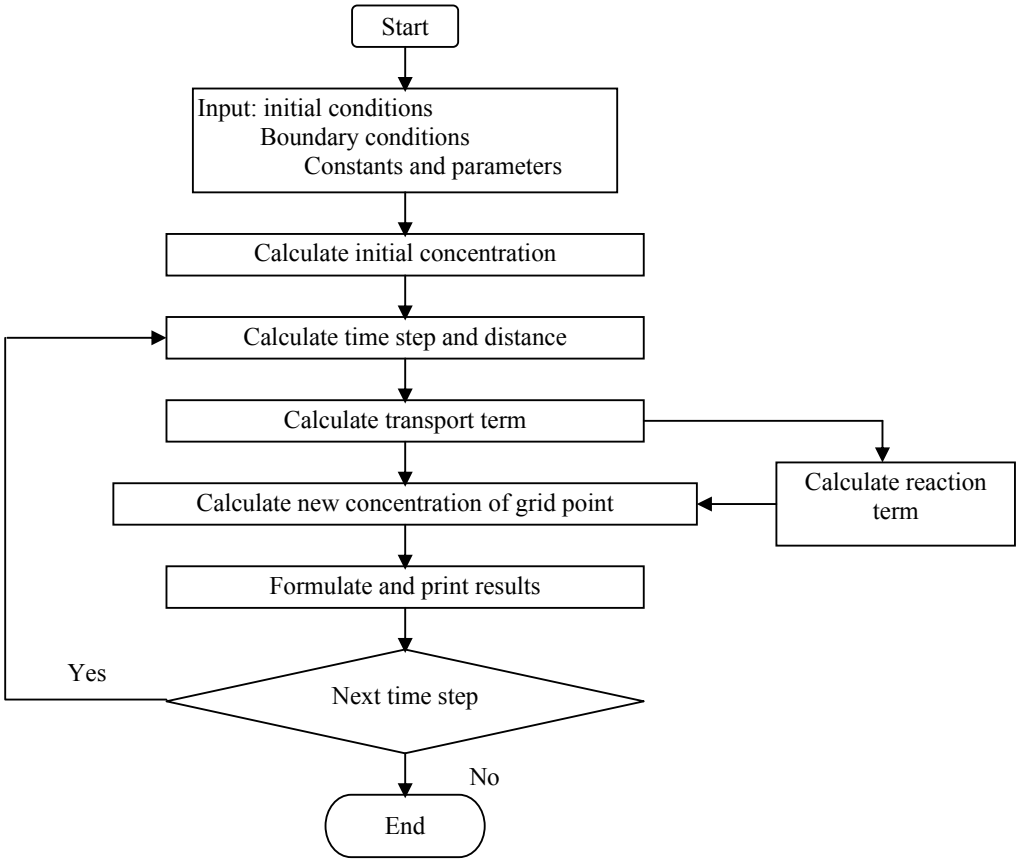

Fig. 3 Flow chart of the simulating the advection-dispersion-reaction and nitrate degradation processes.

Table 5 Parameters used for the simulation.

Biochemical parameter		Parameter values
Exchange coefficient	α	10 day^{-1}
	β	0.005 day^{-1}
	γ	0.00005 day^{-1}
Monod half velocity	K_{CH2O}	0.10 mmol/L
	K_{O2}, K_{NO3}	1.0 x 10^{-3} mmol/L
Aerobic bacteria X	Yield Coefficient Y^{O2}	0.10 mol cell-C/mol OC
	Maximum growth rate v_{max}	5.0 day^{-1}
	Constant decay rate v_{X1dec}	0.75 day^{-1}
Anaerobic bacteria X	Yield Coefficient Y^{NO3}	0.081 mol cell-C/mol OC
	Maximum growth rate v_{max}	4.05 day^{-1}
	Constant decay rate v_{X1dec}	0.75 day^{-1}
Switching function parameter	Threshold concentration of O_2 $[O_2]_{thres}$	1.5 x 10^{-2} mmol/L
	Slope of switch function f_{s1}	40.0
Soil properties	Porosity	0.48
	Dispersivity coefficients	0.1cm

Table 6 Initial and boundary conditions.

Chemical species	Injection water	Initial background concentration		
		Mobile phase	Bio phase	Matrix phase
DO (meq/L)	0.111	0.1	0.1	-
NO_3^- (meq/L)	1.20	0.1	0.1	-
CH_2O (meq/L)	0.186	0.3	0.3	1500.0

Table 7 Calculation conditions.

Calculation depth	50 cm
Calculation period	56 days
Grid mesh size	0.5 cm
Time increment	30 sec
Cross sectional velocity	1.4×10^{-4} cm/sec

4. Results and Discussion

4.1 Experimental results

Flow rate and Permeability

The columns 1, 2, 3 and 4 were initially run at flow velocities of 2.55×10^{-4} cm/sec, 2.55×10^{-4} cm/sec, 3.18×10^{-4} cm/sec and 2.17×10^{-4} cm/sec respectively. After 4 days the flow velocities of columns 1, 2, 3 and 4 were reduced to 8.85×10^{-5} cm/sec, 6.37×10^{-5} cm/sec, 1.06×10^{-4} cm/sec and 8.85×10^{-5} cm/sec respectively. **Figure 4** shows the flow rates in the columns are decreasing during the running time. Calculation of the average velocity and permeability is based on Darcy's Law. **Figure 5** shows the permeability in the columns is decreasing during the running time. The decreases in the permeability are due to clogging of the soil pores as a result of bacteria growth. From the experimental results of flow rate and permeability, however, there is significant increasing in the permeability when sawdust was used.

pH and electrical conductivity

Figure 6 shows the difference between influent and effluent pH. Mean pH influent was 6.8 and effluent pH 6.6, 6.6, 6.5 and 6.6 for columns 1, 2, 3 and 4 respectively.
Related studies [12] have reported that the solutions pH must be maintained below pH 7 for complete reduction of nitrate. Denitrification is related to pH, with an optimum in the range 6.0-8.0, which is typical for heterotrophic organisms generally.

Figure 7 shows the difference between influent and effluent electrical conductivity. Mean electric conductivity of the influent was 0.75 mS/cm. for columns 1, 2, 3 and 4 effluent electric conductivity was 0.7 mS/cm, 0.83 mS/cm, 0.9 mS/cm and 0.68 mS/cm respectively.
The experimental results showed that sawdust column effluent obtained lower value of electric conductivity (0.68 mS/cm), bamboo chip column effluent obtained the higher value of electric conductivity (0.9 mS/cm), and soil column effluent obtained the middle value of electric conductivity (0.7 mS/cm). The higher value of electrical conductivity (EC) obtained from bamboo chip column effluent estimated that the amount of total dissolved salts (TDS), released from bamboo chip is higher than sawdust and soil.

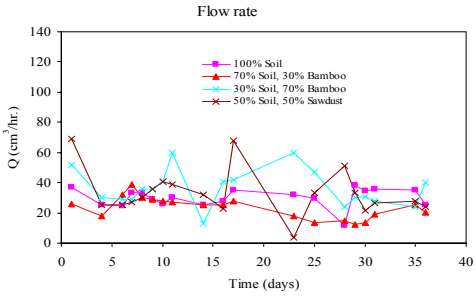

Fig. 4 Flow rate changes during the experiment.

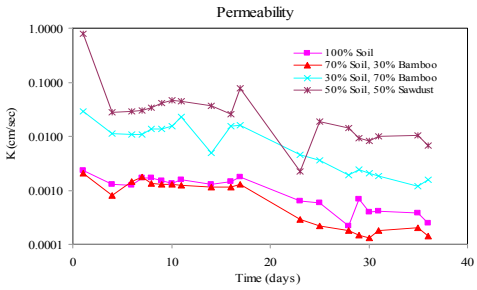

Fig. 5 Permeability changes during the experiment.

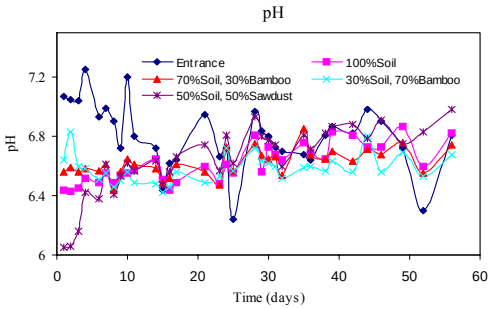

Fig. 6 The experimental results of pH.

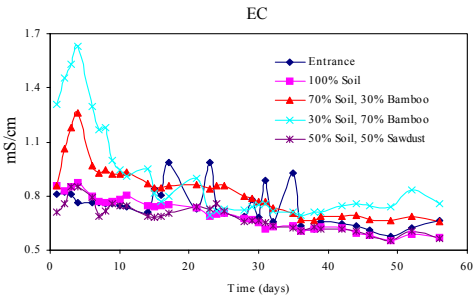

Fig. 7 The experimental results of EC.

4.2 Simulation results

The dependence of oxygen, nitrate, and organic carbon distribution with depth at different time in mobile phase for soil-sawdust is presented in **Fig. 8**, **Fig. 9**, and **Fig. 10** respectively. The model simulation results show that the top 10 cm of soil are most important for oxygen, nitrate, and organic carbon changes. Oxygen concentration reduced at the top of column where oxygen concentration decreased to zero after 36 hours. Denitrification occurred immediately following the reduction of oxygen. Organic carbon increased at the top 35 cm of the column due to dissolved organic carbon from secondary wastewater and solid organic carbon from the sawdust and then decreased due to less arrived of dissolved organic carbon to the column bottom from secondary wastewater.

Figure 11 shows the results of simulated schematic of bacteria growth with time at different depths.Initially the bacteria tend to be acclimated to the new environmental conditions (pH, temperature, nutrients, etc.). Then the living bacteria population increases rapidly with time at an exponential growth in numbers, and the growth rate increasing with time. After that with the exhaustion of nutrients and build-up of waste and secondary metabolic products, the growth rate has slowed to the point where the growth rate equals the death rate. The living bacteria population did not start to decreases with time, due to the sufficient and continues feeding of nutrients, nitrate from injected secondary wastewater and organic carbon from injected secondary wastewater and sawdust or bamboo chip.

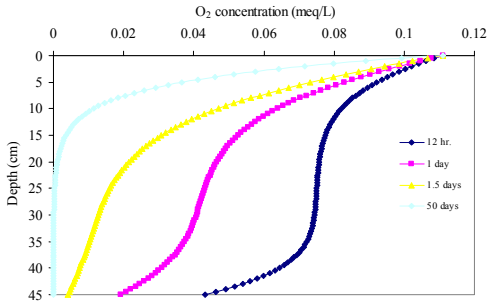

Fig. 8 Simulation results of O_2 concentration for soil-sawdust.

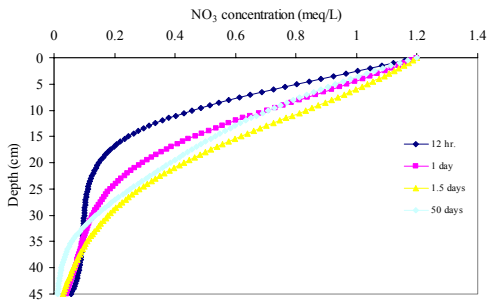

Fig. 9 Simulation results of NO_3^- concentration for soil-sawdust.

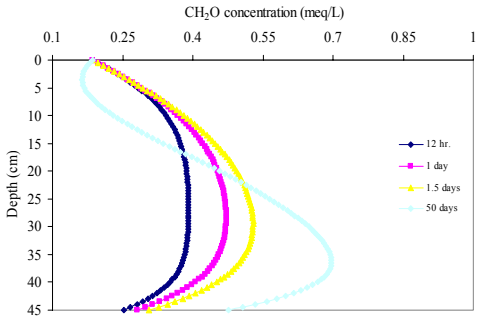

Fig. 10 Simulation results of CH_2O concentration for soil-sawdust.

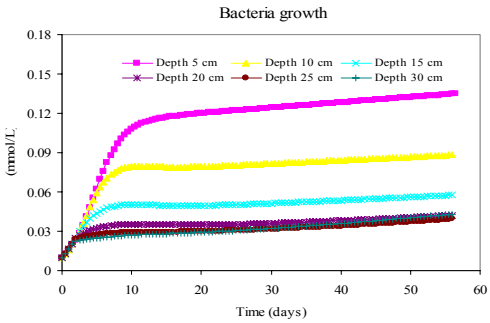

Fig. 11 Simulation results of bacteria growth for soil-sawdust.

4.3 Comparison between measured and simulated data

Nitrate

For columns 1, 2 and 4 (Table 3) good agreement was obtained between simulated and measured concentrations of nitrate as shown in **Fig. 12**. For column 3 was (packed with a mixture of 30% soil and 70% bamboo chip) measured changes of nitrate concentrations differ from simulation results. It can be explained by the fact that bamboo chip contained ammonium.

Carbon

The organic carbon concentration was measured once. The value obtained is in good agreement with simulated value for that time **Fig. 13**. The simulated value obtained by adjusted the concentration of carbon in matrix phase. The simulated and measured results for column 2, 3 and 4 (Table 3) show that the carbon supplied from sawdust and bamboo chip is a sufficient source of carbon to enhance microbial denitrification.

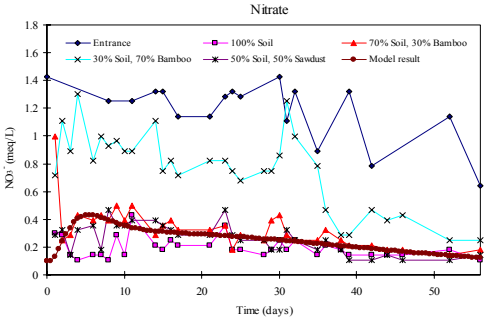

Fig. 12 the comparison between measured and simulated nitrate concentrations.

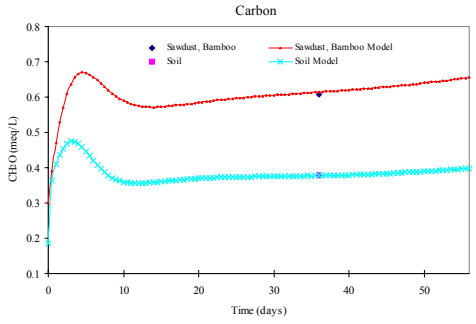

Fig. 13 the comparison between measured and simulated carbon concentrations.

4.4 Discussion

Nitrate

Laboratory column experiments conducted in this study showed significant nitrate reductions. Nitrate reductions of 92.5%, 87.5%, 82.5% and 90% were observed in the columns 1, 2, 3 and 4 respectively. Denitrification was assumed to be the cause of nitrate reductions in the column experiments due to differences in influent and effluent nitrate.

The columns 1, 2, 3 and 4 were run at average permeability of 1.45×10^{-3} cm/sec, 1.24×10^{-3} cm/sec, 1.46×10^{-2} cm/sec and 7.39×10^{-2} cm/sec respectively.

The column 1, packed with soil, showed significant nitrate reductions and low permeability while column 4, packed with mixture of soil and sawdust, showed significant nitrate reductions and high permeability. Additional advantage of using the sawdust and bamboo chip is increased permeability of the column material.

pH conditions in the columns were found to be favorable for denitrification. pH measured in the effluent from the column experiments was always between 6 and 7.

Dissolved oxygen concentrations in all columns were such that denitrification could be assumed to be responsible for reductions in nitrate. While a significant reduction in nitrate was observed between influent and effluent in the columns, also oxygen was being utilized.

The reduction in flow rate observed through all columns after continuous operation exceeding four days suggest a growth of microbial biomass, a by-product of microbial denitrification. Therefore, nitrate reduction in the column experiments is expected to be due to microbial denitrification.

Carbon

The bacteria that mediate the denitrification process require an organic carbon source to metabolizenitrate. The possible sources of this organic carbon are dissolved organic carbon, (supplied with influent secondary wastewater) and solid organic carbon, (supplied in the form of sawdust and bamboo chip). Carbon is used as an energy source for many reactions, not only denitrification. Since anaerobic conditions are established in the columns, the ecological redox sequence, can be consider as this identifies reactions which occur when the oxygen becomes limited. The carbon source provided by sawdust and bamboo chip is more than the required to reduce nitrate from the column experiments conducted in this study. Influent to the column consisted of secondary treated effluent from Wajiro wastewater treatment plant, which was containing much organic carbon concentrations. Therefore it can be assumed that the source of carbon within the columns was from secondary treated wastewater, soil, sawdust, and bamboo chip. It has been previously established that large reductions in nitrate observed in the column experiments were attributed to denitrification. It was thus assumed that the sawdust and bamboo chip in the columns increased both of the permeability and carbon source for denitrification.

Bacteria growth

The growth of microbial biomass has the ability to reduce the effectiveness of the columns while appreciable quantities of carbon are still present. The problem with biomass growth is that it reduces the permeability of the columns, producing more resistance to flow through the columns. Problems with microbial biomass clogging have not been reported in the literature for columns amended with sawdust or bamboo chip. Column clogging from high biomass is considered more of a problem for permeability where large quantities of rapidly degradable liquid carbon are available to remediate contaminated wastewater. This is due to rapid increases in microbial population when food and energy are available in excess.

Chemical components of materials

The chemical components of soil, sawdust and bamboo chip are shown in **Table 4**. The total organic carbon are released from bamboo chip is higher than the soil and sawdust, but the chemical components analysis showed that is carbon availability 44.1% in sawdust higher than the bamboo chip and soil. It indicated that enough carbon can be released from sawdust for long time.

The chemical components of bamboo chip contents more ammonium. In the presence of specific bacteria and oxygen, ammonium is enzymatically oxidized in a stepwise process to nitrite NO_2^- and nitrate NO_3^-. Other chemical components of bamboo chip like potassium K and phosphorus P is higher than the soil and sawdust.

5. Conclusion

The results from this study showed that it was generally possible to simulate the laboratory experimental results with a mathematical numerical model. A detailed comparison between the experimental data and the simulation results showed that good agreement was obtained between measured concentrations of nitrate and model results. The one–dimensional solute–transport model was developed and calibrated.

Experimental results showed that bacteria growth and microbial biomass build-up has the ability to reduce the permeability of the columns, producing more resistance to flow through the columns. This is due to rapid increases in microbial population when food and energy are available in excess. The carbon source utilized in the microbial degradation of nitrate was come from two different sources, dissolved organic carbon from secondary wastewater and solid organic carbon from the sawdust and bamboo chip. While dissolved organic carbon concentrations indicated that enough carbon was being utilized to account for decreases in nitrate.

Sawdust materials have proven to be promising materials for controlling and increasing the permeability and removal of nitrate from wastewater. The results from the laboratory column experiments showed significant reduction in nitrate and increasing the permeability when sawdust was used as a carbon source to enhance microbial denitrification.

The usefulness of denitrification of secondary wastewater using sawdust is dependent on their relative cost to environmental benefit. The cost of installing denitrification system is low using cheap carbon source like sawdust.

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