SIMULATION ON NITROGEN REMOVAL BY WATER HYACINTH SYSTEM

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INTRODUCTION

Nowadays, the role of natural environmental systems on water pollution control has gained more attention among environmental engineers. The main concepts are to make use of the natural ecosystems and appropriate technology which avoids complicated mechanical systems that require high investment cost as well as skilled personnel to control and operate. The use of the natural systems can also help preserve the existing environment. In this study, the role of a water hyacinth pond system in wastewater treatment is investigated. The study is emphasized on development of a computer model to simulate the performance of the system in removal of nitrogen from the secondary-treated wastewater.

ASSUMPTIONS

In this simulation model, the following assumptions are made: (1) Nitrogen removal is mainly due to absorption by water hyacinth which will be periodically harvested. (2) Flow in the pond is plug flow. Influent and recirculated flow are uniformly distributed over the pond cross-sectional area. (3) The growth rate of water hyacinth at different parts in the pond may vary depending upon the availability of nutrients. However, after harvesting the amount of water hyacinth left in the pond is uniformly distributed. (4) No denitrification process occurs in the pond. (5) Nitrogen is the only limiting nutrient.

SCHEMATIC DIAGRAM OF THE POND SYSTEM

The pond is divided into N chambers as shown in Figure 1. In each chamber, a complete-mix condition is assumed. The secondary-treated wastewater with a total flow Q is distributed to each chamber with flow rates Q_1, Q_2,..,Q_n, respectively. A portion of the effluent is recycled to the first chamber at the rate Q_r. Note that $\sum Q_i = Q$, and some Q_i, but not all, may be zero.

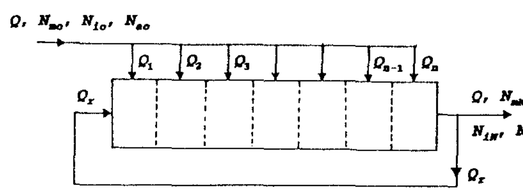

Figure 1. Schematic diagram of the system.

NITROGEN FORMS

It is considered that nitrogen compounds in the pond are in the forms of ammonia, nitrite, nitrate and organic nitrogen in water hyacinth cell tissue. Since the pond is used as a tertiary treatment system, it is assumed that the influent contains nitrogen in the forms of ammonia and nitrate (small amount of nitrite may be present). Both ammonia and nitrate will be absorbed by water hyacinth together with some other nutrients to produce energy and new cells.

SYSTEM KINETICS

In each chamber, mass balance equations for ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and water hyacinth biomass (which is assumed to be linearly proportional to the total amount of nitrogen absorbed) are formulated as follow:

Ammonia Nitrogen:

Chamber No.1: $$V_1\frac{dN_{m1}}{dt} = Q_1N_{mo}+Q_rN_{mn}-(Q_1+Q_r)N_{m1}-U_{m1}W_1-k_{m1}V_1N_{m1} \quad (1)$$

Chamber No.2-N: $$V_i\frac{dN_{mi}}{dt} = Q_iN_{mo}+(Q_r+\sum_{j=1}^{i-1}Q_j)N_{m,i-1}-(Q_r+\sum_{j=1}^{i}Q_j)N_{mi}-U_{mi}W_i-k_{mi}V_iN_{mi} \quad (2)$$

Nitrite Nitrogen:

$$\text{Chamber No.1:}\quad V_1\frac{dN_{i1}}{dt}=Q_1N_{io}+Q_rN_{in}-(Q_1+Q_r)N_{i1}+k_{m1}V_1N_{m1}-k_{i1}V_1N_{i1} \tag{3}$$

$$\text{Chamber No.2-N:}\quad V_i\frac{dN_{ii}}{dt}=Q_iN_{io}+(Q_r+\sum_{j=1}^{i-1}Q_j)N_{i,i-1}-(Q_r+\sum_{j=1}^{i}Q_j)N_{ii}+k_{mi}V_iN_{mi}-k_{ii}V_iN_{ii} \tag{4}$$

Nitrate Nitrogen:

$$\text{Chamber No.1:}\quad V_1\frac{dN_{a1}}{dt} = Q_1N_{ao}+Q_rN_{an}-(Q_1+Q_r)N_{a1}-U_{a1}W_1+k_{i1}V_1N_{i1} \tag{5}$$

$$\text{Chamber No.2-N:}\quad V_i\frac{dN_{ai}}{dt} = Q_iN_{ao}+(Q_r+\sum_{j=1}^{i-1}Q_j)N_{a,i-1}-(Q_r+\sum_{j=1}^{i}Q_j)N_{ai}-U_{ai}W_i+k_{ii}V_iN_{ii} \tag{6}$$

Water Hyacinth Biomass:

$$\text{Chamber No.1-N:}\quad \frac{dW_i}{dt} = G_{wm}U_{mi}W_i + G_{wa}U_{ai}W_i \tag{7}$$

where N_{mi}, N_{ii}, N_{ai} and W_i are respectively ammonia nitrogen, nitrite nitrogen, nitrate nitrogen concentrations and water hyacinth biomass in the i^{th} chamber; N_{mo}, N_{io} and N_{ao} are ammonia nitrogen, nitrite nitrogen and nitrate nitrogen in the influent; Q_i is the wastewater feeding rate to the i^{th} chamber; Q_r is the recycled flow rate; U_{mi} and U_{ai} are the ammonia and nitrate uptake rates by water hyacinth; V_i is volume of the i^{th} chamber; k_{mi} and k_{ii} are the first-order decaying rates of ammonia and nitrite; G_{wm} and G_{wa} are the amount of water hyacinth biomass produced per unit weight of ammonia nitrogen and nitrate nitrogen absorbed, respectively. The uptake rates U_{mi} and U_{ai} are non-linear functions of ammonia and nitrate concentrations, temperature, and light intensity.

The above mentioned mass balance equations can be written in the matrix form as follow:

$$\frac{d\mathbf{N_m}}{dt} = \mathbf{A_m}.\mathbf{N_m} - \mathbf{U_m}.\mathbf{W} + \mathbf{Q_m} \tag{8}$$

$$\frac{d\mathbf{N_i}}{dt} = \mathbf{A_i}.\mathbf{N_i} + \mathbf{K_m}.\mathbf{N_m} + \mathbf{Q_i} \tag{9}$$

$$\frac{d\mathbf{N_a}}{dt} = \mathbf{A_a}.\mathbf{N_a} - \mathbf{U_a}.\mathbf{W} + \mathbf{K_i}.\mathbf{N_i} + \mathbf{Q_a} \tag{10}$$

$$\frac{d\mathbf{W}}{dt} = (G_{wm}.\mathbf{U_m} + G_{wa}.\mathbf{U_a})\mathbf{W} \tag{11}$$

SOLUTION TECHNIQUE AND CONCLUSION

Since the mass balance equations shown above are non-linear, an iteration technique must be employed in each time step. With the assumed initial conditions at time t_1, Eqs.8–11 are solved to obtain the values of NH_3–N, NO_2–N, NO_3–N and water hyacinth biomass in each chamber at time t_2. Then, the averaged values of these variables between time t_1 and t_2 are computed. The computation is then repeated by using these averaged values on the right-hand side of Eqs.8–11. However, it has been found that iteration is not necessary when time increment is not too high. The computation is then continued to the next time step. The obtained results show the spatial and temporal variations of nitrogen in various forms and growth pattern of water hyacinth in the pond.

With an aid of this simulation model, nitrogen removal efficiency of the water hyacinth pond system can be evaluated. Comparison can be made among different system configurations and parameters, e.g., influent feeding pattern and loading, recirculation ratio, water hyacinth density and harvesting interval, etc. Since the growth of water hyacinth and nutrient uptake rates are dependent on climatic condition, a field study to determine the proper values to be used in the model is necessary.