Chapter 5

CONCLUSIONS

The present study was undertaken to have an engineering insight into the nutrient removal mechanisms and to study the kinetics of nutrient removal in RZTS for domestic wastewater. This was achieved through strategic studies in various parts exploring the nutrient removal processes occurring within RZTS in comparison with reference reactors. The first part dealt with evaluation of selected bed media and various macrophytes to know their combination specific (macrophyte and media) performance for the nutrient removal in up-flow mode of RZTS. A better combination was identified based on their comparative performance appraisal. The identified combination was used in lab-scale experimental set-up of RZTS to study its nutrient removal capabilities and the mechanisms responsible for the removal. The different reaction kinetic models were developed based on different approaches and assessed for predicting the nitrogen levels within RZTS. Finally, field-scale experiments were conducted to study the removal of nutrients from septic tank effluent by RZTS. The kinetic models developed earlier were applied to predict nutrient concentrations and comparative study was carried out for predicted and actual values.

Following are the conclusions drawn based on the extensive studies carried out on nutrient removal in RZTS.

5.1 Identification of Desirable Combination of Macrophyte and Media

There are few extensive studies conducted in the Indian context to evaluate the performance of different aquatic macrophytes grown in various kinds of bed medium. In the present study, different combinations of aquatic macrophytes and bed media were assessed for nutrient removal potential from synthetic wastewater using subsurface RZTS. Various lab – scale RZTS were developed using selected macrophytes, *Typha Latifolia, Colcacia Antiquorum, Canna Indica,* and *Phragmites Australis* in combination with stone grit, plastic granules and sand as bed medium. A desirable alternative was worked out based on this study. In order to evaluate potential of macrophytes, reference reactors were established without macrophytes. Following are the conclusions drawn based on this part of the study.

1. All the bed media used in reference reactors had 43% to 55% efficiency for nutrient removal. Also, the use of these media in planted reactors found to support growth of all the macrophytes used in the study.

2. The use of the plastic granules in reference reactor showed that, its potential for nutrient removal is higher than that of stone grit and sand. However, in planted reactors it does not support growth of all kinds of macrophytes. Also, its individual removal potential was suppressed in combination with *Colcacia Antiquorum* and *Phragmites Australis*.

3. The mineral content in the media seems to be non extractable and did not have much contribution for nutrient removal by chemical precipitation. For all the media, physical parameters are dominant factors affecting nutrient removal.

4. All the macrophytes viz. *Typha Latifolia, Colcacia Antiquorum, Canna Indica,* and *Phragmites Australis* have different growth and nitrogen removal rates in stone grit, sand and plastic granules under same environmental conditions. With the exception of plastic medium, the nutrient removal performance of all the RZTS combinations was found to be higher than that of reference reactors. Almost all combinations took 45 to 60 days to give steady performance of nutrient removal.

5. *Colcacia Antiquorum* had highest growth rate of 0.016 d^{-1} in plastic granules. But the nitrogen removal rate by this plant was higher (1.3 d^{-1}) in sand medium. *Colcacia* with sand can be a potential combination. But the plant does not have dense lateral spread and may provide lesser surface area for bacterial attachment.

6. *Canna Indica* has comparatively better growth rate (0.03 d^{-1}) in sand and stone grit medium. But the nitrogen removal rate by this plant was higher (1.6 d^{-1}) in sand medium. *Canna Indica,* which is an ornamental plant with soft tissues, was

observed to be easily susceptible to diseases and insect attack. Hence this plant is not suitable for the usage in RZTS.

7. The growth parameter of ***Phragmites Australis*** was found to be highest (0.029 d^{-1}) in stone grit medium. It performs better with sand bed medium and has N removal reaction rate parameter of 1.22 d^{-1}. Phragmites with stone grit can be a potential combination. This plant is reported to be very invasive. Hence not preferable for its use in RZTS.

8. *Typha Latifolia* was better grown in stone grit medium having highest growth parameter of 0.034 d^{-1}. It has N removal reaction rate parameter of 1.27 d^{-1} and 1.39 d^{-1} in stone grit and plastic at 75 days after plantation respectively. Typha with stone grit and plastic can be a potential combination. But, the growth rate of this plant is small (0.02 d^{-1}) in plastic medium.

9. The P removal performance of macrophyte and bed media combinations did not vary to very great extent in relation with macrophyte and media characteristics. For all the combinations P removal was found to be ranging in 42% to 48%.

10. The RZTS created with random selection of aquatic plants or naturally colonizing plants with arbitrarily chosen media may not give desired performance. The selection of macrophyte and medium combination characterized by higher nutrient removal in lab scale study would provide greater efficiency in actual condition.

11. The growth rate and nutrient removal capabilities of the macrophytes are not related to each other. The combination of stone grit and *Typha* was chosen to be an appropriate combination based on high growth rate, adequate nutrient removal potential, cost effectiveness, convenient operation and maintenance, local availability, easier plantation, non invasive nature and resistance to insects attack.

5.2 Laboratory Scale Study of *Typha* and Stone Grit Combination

The RZTS with combination of *Typha* plants and stone grit medium was subjected for extensive studies in a lab scale set up. The system was assessed for its nutrient removal performance at various HRTs using feed of synthetic wastewater. The study was conducted and results were analyzed for different stages of plant growth. The reference reactor with stone grit medium was also used in the study to know contribution of plants in nutrient removal. The period between plantation and fully grown vegetation with consistent performance for nutrient removal in the RZTS is designated as initial period. The period during which RZTS has fully grown vegetation and performing consistently for nutrient removal is designated as established period. Following are the conclusions drawn based on this part of the study.

1 In the initial period, the nutrient removal performance of RZ bed goes on increasing with HRT. In the RZ bed, TKN and P - removal was found to be 93% and 63% respectively at 56 days HRT. The initial period is characterized with inconsistent behavior, increased concentrations of TKN, small reduction in NH_4- N, small nutrient uptake by plants and dominance of denitrification over nitrification.

2 The established period for *Typha* and stone grit RZTS is at least 45 days for consistent nutrient removal. The presence of *Typha* plants provide favorable conditions for simultaneous nitrification and denitrification to occur within the RZTS after the initial period.

3 The evapotranspiration loss of *Typha* and stone grit RZTS is 3 cm/ day (10% of inflow).

4 The NH_4 -N adsorbed around the particles of bed material was found to be 0 mg/gm, 0.015 mg/gm, and 0.016 mg/gm of stone grit media at 0^{th}, 60^{th}, and 120^{th} days respectively. Though some removal was observed due to adsorption in initial 60 days, there was very small change in adsorption level over next 60 days. Thus, the negligible change in adsorbed NH_4 -N levels around particles indicates that

adsorption phenomenon is not a dominant mechanism for NH_4 - N removal in established period.

5 The P sorption capacity of stone grit medium is 0.02 mg/gm of the medium and will be used up within initial four months.

6 The nitrogen uptake of *Typha* plants is 1176.11 kg/ha.year. The nitrogen storage of Typha plant in roots is higher (38%) as compared to leaf (31%) and stem (31%).

7 The phosphorus uptake of *Typha* plant is 147.89 kg/ha.year. The root, stem and leaves contribute 40%, 36% and 24% for P- storage respectively. It can be deduced based on this observation that *Typha* uptake alone contributes about 24% of P-removal.

8 As compared to N - uptake values, P - uptake values are less, indicating lesser P-demand of *Typha* for its growth.

9 The P - removal was found to be 21.76% at 7.5 days HRT. In the reference reactor P removal was found to be 4.17%. Adsorption being common in both the reactors plant uptake was the only mechanism to cause the enhanced removal.

10 Almost all TN was found to be removed in the RZTS at 7.5 days HRT. The contribution of *Typha* plants, denitrification and adsorption is 74%, 23% and 3% in TN removal respectively. Thus, *Typha* uptake is dominant in total N removal.

5.3 Field Scale Study of *Typha* and Stone Grit Combination

This part of the work was intended to study nutrient removal performance of *Typha* and stone grit combination for septic tank effluent in comparison with that of reference reactor. The effect of variable nutrient loadings and mechanism of the nutrient removal was studied and the results obtained from the field scale were compared with lab scale studies. Following are the conclusions drawn based on this part of the study.

1. TN removal was found to be 56% and 50% in RZ and reference reactor respectively. The sedimentation and filtration of solids, nitrification, denitrification and plant uptake are responsible mechanisms for TN removal in the field scale RZ bed.

2. *Typha* plants are main responsible bio-agents for nitrification and denitrification reactions in RZ bed. The rate of nitrification increases with HRT and is higher during HRT of 4.5 to 6 days. The rate of denitrification was low.

3. The rate of nitrification was found to be almost same in both, lab-scale as well as field-scale RZ bed. However denitrification was found to be suppressed possibly due to lack of organic carbon source in field-scale RZ bed. This seems to be main reason to cause lower removal of N in field- scale RZ bed as compared to lab- scale RZ bed.

4. The removal of TN goes on decreasing with increase in its loading. The *Typha* and stone grit RZTS can be loaded up to 20 kg/ha.d to achieve 40% to 55% removal. Also HRT beyond 4.5 days is not beneficial as there was not much change in TN removal beyond this HRT.

5. The removal of P goes on decreasing with increase in its loading. The *Typha* and stone grit RZTS can be loaded up to 15 kg/ha.d to achieve 20% - 55% removal. Also HRT beyond 6 days is not beneficial as there is not much change in P - removal beyond this HRT.

6. The removal of P was found to be higher in field-scale RZ bed as compared to that in lab-scale RZ bed. This is attributed to dense stand of plants and removal of particulate P due to intermingled mass of roots and rhizomes in the RZ bed. It can be assumed based on lab-scale studies, that the role of adsorption is insignificant for P removal in this case also. Also, the removal of P via phosphine emission appears to involve with only small magnitude for P removal.

5.4 Kinetics of RZTS

The reaction kinetic models were developed for the simulation of nitrogen concentrations within a RZTS based on the lumped and distributed parameter approaches. The conditions within the RZTS for the development of lumped parameter model were assumed to be either plug flow, completely mixed or dispersed. The processes considered in the distributed parameter model for nitrogen transformations were ammonification, nitrification, plant uptake and denitrification. The reaction rate parameters of both the models were estimated by nonlinear least square analysis using the nitrogen values obtained from laboratory scale experiments. The model simulated nitrogen concentrations were compared with those observed in the field scale experiments.

1. The lumped parameter approach shows that the nutrient concentrations are better predicted by plug flow and complete mix conditions in the planted and reference reactors respectively.
2. The reaction rates for the removal of nitrogen forms are higher by 2.5 times in planted reactor than the reference reactor.
3. The plant uptake contributes more for the removal of nitrate than denitrification.
4. The contributions from nitrification and plant uptake for the removal of ammonia nitrogen are nearly same.
5. The denitrification rates are higher than nitrification rates in the reference reactor.
6. Both lumped and distributed parameter models are useful in predicting the nitrogen concentrations in RZTS. However, the relative contributions from various processes of nitrogen removal can be estimated by the use of distributed parameter model.
7. The nitrogen values predicted by the models and those observed in the field-scale study are different suggesting higher reaction rates in laboratory scale studies.
8. The developed simulation model can be used as a RZTS planning and design tool for the effective control and treatment of nutrient induced pollution.