AN EXPERIMENTAL RESEARCH ON APPLICATION OF SUB-SURFACE FLOW CONSTRUCTED WETLANDS FOR MEAT PROCESSING INDUSTRY EFFLUENT TREATMENT AND NUTRIENT REMOVAL

By

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This thesis is presented for the degree of Doctor of Philosophy in

Environmental Engineering

Division of Science and Engineering

Murdoch University, Western Australia

March 2007

The Ph.D research was funded by MINTRAC – National Meat Industry Training and Advisory Council Limited.

To two great people in my early education:

The Late Vasukutti Amma, my first teacher, who taught me the alphabets

&

The Late Nalan Sir, who introduced me to the wonderful world of mathematics

DECLARATION

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

Rajendra G Kurup

Publications from this research

1. Rajendra G Kurup, (2007) “Synthesis and application of a product for phosphorus removal from wastewater and polluted water bodies”, Provisional Patent submitted to IP Australia, (Chapter 9).
2. Kurup, R and Pullammanappallil, P. (2004). “A review of processes and design methods for organic matter removal in sub-surface flow constructed wetlands treating municipal and industrial wastewaters*”. Sustainability of Water Resources*, IWA Publications, London, pp 232-240, (Chapter 3).
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6. Kurup, R (Under review), “COD removal dynamics of sub-surface flow constructed wetlands with vetiver grass as emergent vegetation under different nitrogen species*”*, *ASCE Journal of Environmental Engineering* (Submitted in 2006), (Chapter 6).

7. Kurup, R (Under review), “Nitrogen removal dynamics in experimental sub-surface flow constructed wetlands with vetiver grass as emergent vegetation” Submitted to *Environmental Science and Technology* in 2006), (Chapter 7).

8. Kurup, R (Under review), “Phosphorus removal in sub-surface flow constructed wetlands during nitrification and denitrification with *Chrysopogon zizanioides* as emergent vegetation. Submitted to *Environmental Science and Technology* in 2006, (Chapter 8).

9. Kurup, R (under preparation), A critical review of nutrient removal in sub-surface flow constructed wetlands, to be communicated to *Critical Reviews in Environmental Science and Technology,* (Chapters 4 & 5).

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Acknowledgements

I am greatly indebted to MINTRAC - National Meat Industry Training Advisory Council Limited- for the generous funding for the PhD research. My special thanks to Ms Margaret Tayar (former Director), Ms Jenny Kroonstuive (Director) and the Project Officers Ms Margaret Antony and Ms Jodie Hummerston. The staff members of MINTRAC have always been very friendly and supportive.

I have a number of people at Murdoch University to acknowledge and thank, which include, but not limited to, Prof Goen Ho, who acted as my supervisor in the final stages, Dr Pratap Pullammanappallil, who supervised the research in the early stages, Ms Karen Olkowski, Research Degrees Officer, Mr Steven Goynich and Dr Ralf Cord-Ruwisch.

Undertaking a PhD while raising a young child and running an engineering consulting firm is a very demanding task, particularly, when one does not have the luxury of the extended family support. I have no words to express the depth of my gratitude to my wife Biji for her strong support (while immersed in her own PhD) and my daughter Thankam for her understanding during the past few years. One thing my daughter would never forget to ask me in the past few years was that when I would be finishing my PhD. I take this opportunity to thank my eldest brother, who has always inspired me with his professionalism.

Last but not the least I thank all my friends who have been emotionally supportive to us, especially Balu, Tony and the Mathews.

ABSTRACT

Meat processing industries produce large volumes of high strength wastewater. Conventional technologies used in Australia and similar countries for treatment of effluent from meat processing and similar industries, such as wineries and processed food industry, are treatment ponds with or without a mechanical treatment system.

A properly designed activated sludge treatment system would be capable of biological removal of phosphorus and nitrogen in addition to BOD_5. These systems, however, require substantial electrical power, skilled operational support and produce large quantities of biosolids or sludge which require further on-site treatment or off site disposal. Application of sub-surface flow constructed wetland (SSF-CW) systems could provide a sustainable solution for treatment of meat processing industry effluent and other similar high strength wastewaters. There are, however, only very limited studies on application of SSF-CW for secondary treatment of high strength wastewaters. Although there have been a number of cases where SSF-CW have been used as the secondary treatment unit for municipal wastewater, this technology has not still become a common practice for the same purpose in Australia. Most of the applications are for either polishing of secondary or tertiary treated municipal wastewater or for greywater treatment.

This research was funded by National Meat Industry Advisory Council (MINTRAC). Sustainable wastewater treatment has been taken up as a very important issue by meat industry. The industry provides Ph.D research scholarships through MINTRAC to

develop new technologies for wastewater treatment and nutrient removal from meat processing effluent.

The main objective of the research was to develop process engineering design parameters for sub-surface flow constructed wetland (SSF-CW) with Monto vetiver (*Vetiveria zizanioides* recently reclassified as *Chrysopogon zizanioides*) as the emergent vegetation for treatment of high strength, nutrient rich wastewater. The study also investigated the phosphorus retention properties of pea gravel for use in SSF-CW system as bed media or as an external phosphorus removal system for meat processing industry effluent. In addition, chemical methods for phosphorus removal from meat processing industry effluent were also investigated.

The thesis is based on experimental research. The research consisted of three types of experimental set up; a) using two laboratory experimental SSF-CW reactors (one with vetiver grass and the other reactor with no vegetation) in a greenhouse with batch feeding of artificial wastewater that simulates meat industry effluent, b) experiment with pea gravel of different particle sizes and solutions of different phosphorus (P) concentrations in a constant temperature room, c) laboratory experiment using actual meat processing industry effluent with alum and sodium aluminate for P removal.

The structure of the thesis is as follows. Following the Introduction is the section of Literature Review, then sections on the experiments that follow a journal paper format, followed by a General Discussion, Conclusions and Recommendations. A list of references is provided at the end of the thesis.

The literature review section has four chapters (Chapter 2 to Chapter 5). Chapter 2 describes a review of meat processing industry effluent characteristics and current treatment technologies. Chapter 3 is a critical review of current literature on COD removal using sub-surface flow constructed wetlands (SSF-CW). Chapter 4 and 5 describe a review of various processes and models on the fate of nitrogen and phosphorus in SSF-CW system respectively.

Chapters 6 to 10 deal with experimental research part of the thesis. Chapters, 6, 7 and 8 share a common methodology section which is described in Chapter 6. Results of the batch experiments with the laboratory SSF-CW systems on COD removal, nitrogen removal and phosphorus retention are discussed in Chapters 6, 7 and 8 respectively. Chapter 9 explains a detailed experimental study on phosphorus adsorption dynamics of pea gravel. Chapter 10 discusses the results on experiments using sodium aluminate and aluminium sulphate for P removal from meat processing industry effluent as an alternate P removal method for such effluent.

An overview of the major results of the experimental section is discussed in chapter 11, in the General Discussion section. Conclusions and Recommendations of the research are provided in Chapter 12.

In this study, it was observed that Monto vetiver grass performed better during nitrification than in denitrification, where the plant did not survive. Ammonium N removal followed a first order decay in both vegetated and un-vegetated experimental SSF-CW system with average removal ranging from 40 to 60 % of the influent. Denitrification was found to be the pathway for nitrate removal. As long as the carbon source was available, the denitrification followed a first order exponential decay, with

over 80% of nitrate was removed in 48 hours. Vetiver grass sustained elevated ammonium levels of approximately 200 mg/L or more, however it was under stress during denitrification and it eventually died.

The experimental SSF-CW systems with pea gravel as bed media could effectively retain soluble reactive phosphorus (SRP) in the wetland cells during experiments of COD reduction and nitrification (with ammonia and high COD input). However, during denitrification study, both experimental SSF-CW cells did not show significant removal of SRP from wastewater. The vegetated cell removed nearly 50% of the input SRP, however, the un-vegetated cell did not show any trend for SRP removal, and in some cases the effluent SRP was nearly 90% of the input value.

The role of Monto vetiver grass for N and P removal was found to be very minor and this study concluded that nutrient removal (N & P) by plant uptake could be neglected in the design of SSF-CW system with Monto vetiver grass.

Adsorption is the major mechanism for P removal from the experimental SSF-CW systems, where pea gravel was used as bed media. The P adsorption capacity of pea gravel increased with decrease in particle size. For 16 to 18 mm, the Langmuir adsorption maximum was 99 mg/kg, whereas for very fine pea gravel powder (<150 μm) the maximum adsorption observed experimentally was 3950 mg/kg. In a typical wetland with pea gravel as bed media for meat processing industry, the media would be capable of P retention for about 2 to 3 years of operation. Supplementary chemical removal method is needed for sustainable P removal once the adsorption maximum of wetland cell is reached.

A chemical P removal system using liquid alum and NaOH for pH stabilisation is more appropriate than sodium aluminate. Application of sodium aluminate for P removal for meat processing industry effluent is found to be less effective as it would need higher dosage, longer settling period, coloured supernatant, acid addition for pH adjustment. Liquid alum application rate is recommended to be between a molar ratio of Al: P of 3 for TP value of <1 mg/L in the treated effluent.

This research study concludes that horizontal flow SSF-CW system with Monto vetiver grass is suitable for COD removal and nitrification from high strength wastewater. Current design equation of horizontal flow SSF-CW system is mostly plug flow exponential decay method, but in this study, it has been concluded that retarded first order rate constant is the most appropriate design method for horizontal flow SSF-CW system for COD removal.

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