Biological Phosphorus Removal by Microalgae in Waste Stabilisation Ponds

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Abstract

Waste stabilisation ponds (WSP) are an important wastewater treatment technology used by thousands of communities around the world. Unfortunately, phosphorus removal in WSP is generally low and inconsistent. The aim of this work was to investigate biological phosphorus removal by microalgae in WSP. Luxury uptake of phosphorus, which is the accumulation of polyphosphate, is known to occur in microalgae in natural systems such as lakes; however, this mechanism has not previously been studied under WSP conditions. Three methods were used in the laboratory to investigate luxury uptake and it was shown for the first time that luxury uptake of phosphorus can occur in microalgae under typical WSP conditions. Acid-insoluble polyphosphate (AISP) is a form of phosphorus storage and acid soluble polyphosphate (ASP) is used for synthesis of cellular constituents. However, the findings of this thesis indicate that ASP may also act as a form of short term storage. The environmental factors influencing luxury uptake were investigated using laboratory experiments conducted under controlled conditions. The key environmental factors were the phosphate concentration in the wastewater, light intensity and temperature. A higher phosphate concentration increased the amount of ASP accumulation and also resulted in AISP being stored within the cells instead of being consumed for growth. Higher light intensity increased ASP accumulation, but as a consequence of elevated growth, the ASP was rapidly consumed. Temperature influenced the rate of AISP accumulation and little if any was accumulated at low temperatures. The fate of polyphosphate in the sludge layer was also studied and it was shown that polyphosphate was degraded resulting in phosphate release. Therefore, to maximise phosphorus removal the microalgae needs to be harvested. Field work showed that at times the biomass contained almost four times the amount of phosphorus required for growth which confirms that luxury uptake does indeed occur in full-scale WSP. To improve phosphorus removal in WSP both luxury uptake and the biomass concentration need to be maximised simultaneously. With this new understanding of biological phosphorus removal in WSP and the key environmental factors required it may be possible to develop a new phosphorus removal process utilising luxury uptake by microalgae.

Acknowledgements

First to my supervisors Prof. Andy Shilton, Dr. Steven Pratt and Prof. Yusuf Chisti for their help, guidance and motivation throughout my research. Their support during my PhD and all the valuable feedback on the many drafts of the research papers is greatly appreciated.

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Finally thank you to all my friends and family for their support during my PhD.

Table of contents

Structure of the thesis

The results and discussion chapters of this thesis are presented as a series of scientific papers. These papers have either been accepted for publication or submitted for review. Consequently there is some repetition in these chapters particularly in the introduction and methods sections. To reduce repetition the introduction sections of the papers have been shortened. A preface is included for each of these chapters to help link the chapters together and illustrate how each of these chapters contribute to investigating the objectives of this thesis.

The content of the chapters is the same as the published paper they are based on; however, some formatting changes have been made to ensure consistent style within the thesis. For example the labels for the Figures and Tables have been modified to include the chapter number (eg Figure 2 changed to Figure 3.2). The chapters have also had some minor editing for improved clarity. Where the published papers refer to other papers within the thesis, these references have been changed to the relevant chapter within the thesis. A summary of the main findings of the research presented in the publications is then given in Chapter 8.

The structure of this thesis complies with the Massey University guidelines given in the Doctoral Handbook, 2008.

List of papers and contribution

A number of chapters in this thesis are based on papers that have been accepted for publication in international peer reviewed scientific journals or presentation at peer reviewed conferences. A list of the chapters and relevant publications is given below.

Chapter 1

Parts of this chapter are based on the introduction from the following publication:

Powell, N., Shilton, A., Chisti, Y., & Pratt, S. (2009). Towards a luxury uptake process via microalgae – Defining the polyphosphate dynamics. *Water Research, 43(17), 4207-4213.*

Chapter 2

Powell, N., Shilton, A., Pratt, S., Chisti, Y., & Grigg, N. (2006). Factors effecting biological phosphorus removal in waste stabilisation ponds – A statistical analysis. *Paper presented at the 7th IWA Specialist Conference on Waste Stabilisation Ponds, Bangkok, Thailand.*

Chapter 3

Powell, N., Shilton, A., Pratt, S., & Chisti, Y. (2006). Luxury uptake of phosphorus by microalgae in waste stabilisation ponds. In R. Stuetz & L. Teik-Thye (Eds.), *Young Researchers 2006 (Water and Environment Management Series no. 12)* (pp. 249-256). London: IWA Publishing.

Chapter 4

Powell, N., Shilton, A., Pratt, S., & Chisti, Y. (2008). Factors influencing luxury uptake of phosphorus by microalgae in waste stabilisation ponds. *Environmental Science and Technology, 42(16), 5958-5962.*

Chapter 5

Powell, N., Shilton, A., Chisti, Y., & Pratt, S. (2009) Towards a luxury uptake process via microalgae – Defining the polyphosphate dynamics. *Water Research, 43(17), 4207-4213.*

Chapter 6

Powell, N., Shilton, A., Pratt, S., & Chisti, Y. Phosphate release from waste stabilisation pond sludge – Significance and fate of polyphosphate. *To be submitted.*

Chapter 7

Powell, N., Shilton, A., Chisti, Y., & Pratt, S. (2009). Luxury uptake of phosphorus by microalgae in full-scale waste stabilisation ponds. *Paper presented at the Water New Zealand Conference, Water 2020: From fragmentation to efficiency, Rotorua.*

All the research that these papers are based on was conducted during my PhD. While the papers were completed with advice and editing from my supervisors Prof. Andy Shilton, Dr. Steven Pratt, and Prof. Yusuf Chisti I designed the experiments, conducted all experimental work, analysed the results and was lead author on all the papers.