

An Investigation of the Biochemistry of Biological Phosphorus Removal Systems

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(ABSTRACT)

Although enhanced biological phosphorus removal (EBPR) and complete biological nutrient removal (BNR) systems can be operated successfully by experienced operators, the accuracy of design and strength of the scientific background need to be reinforced to enable accurate modeling and economically optimal design. One way to accomplish this would be through a better understanding of the biochemical mechanisms and microbial population dynamics that determine the reliability and efficiency of EBPR, and the utilization of this information to improve the design and operation of BNR plants. Such knowledge will also contribute to better structure of modeling tools that are used for design and educational purposes. The current body of knowledge is limited to observational studies that lack detailed biochemical explanations backed with a series of well planned experiments, and this has introduced uncertainties and inaccuracies into the biochemical and design models. Therefore, this study mainly covers a biochemical survey of the underlying metabolisms of active populations in BNR sludges. BNR biomass with biological phosphorus removal (BPR) capability was cultivated in continuous flow reactor (CFR) systems, configured as either University of Cape Town (UCT) and anoxic/oxic (A/O) systems. Following an acclimation period at 20°C, low temperature stress (5°C) was imposed on one UCT system for investigation of the response of the microbial consortium responsible from EBPR activity under cold temperature. Once a stable population with EBPR capabilities is established in each system, activities of ten enzymes that are hypothesized to be taking part in the EBPR metabolism were measured. These enzymes were selected among those that take part in major known pathways of bacterial energy and growth metabolism. Also, ¹³C-NMR was used as a tool to monitor the flux of labeled carbon in and out of pools of cellular storage; i.e. glycogen and polyhydroxyalkanoates (PHA). Combining the gathered information,

accurate mass balances of carbons and reducing equivalents were calculated, eventually leading to determination of the biochemical pathways utilized by the EBPR consortium. Additionally, anaerobic stabilization of COD, a long debated but empirically established phenomenon, was addressed during the study. Considering the pathways proposed to be operative under different conditions imposed on the EBPR systems, a biochemical explanation for the occurrence of COD stabilization in wastewater treatment systems that incorporate anaerobic zones was proposed. Accordingly, depending on the pathways actively used by a microbial consortium, electrons stored in NADH and FADH₂ can either be transferred to the terminal electron acceptor, oxygen, or they can be incorporated into storage polymers such as glycogen for future use. Such differences in metabolism reflect in the quantity of the oxygen consumed in the aerobic reactors. Thus, the correct incorporation of anaerobic stabilization of COD into process design would reduce design aeration requirements and result in economic savings during both construction and operation.

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TABLE OF CONTENTS

INTRODUCTION	1
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CHAPTER I: LITERATURE REVIEW

Introduction.....	4
Background.....	6
Biochemical Background on Metabolic Pathways.....	6
Glycogen as a Storage Product	17
PHAs as Carbon and Energy Storage Product.....	19
Enhanced Biological Phosphorus Removal and the Role of Storage Products.....	22
Analysis of the Research That Followed the Establishment of Initial Models.....	26
Glycogen Metabolism.....	35
Anaerobic COD Stabilization.....	43
References.....	45

CHAPTER II: IMPACT OF THE FEED COD/TP RATIO ON THE INTRACELLULAR STORAGE MATERIALS AND SYSTEM PERFORMANCE OF BIOLOGICAL PHOSPHORUS REMOVAL

Abstract.....	53
Introduction.....	54
Materials and Methods.....	56
Results and Discussion.....	60
Conclusions.....	77
References.....	78

CHAPTER III: BIOCHEMISTRY OF THE ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL SYSTEMS

Abstract.....	81
Introduction.....	82
Materials and Methods.....	100
Results and Discussion.....	113
Conclusions.....	147
References.....	149

**CHAPTER IV: THE IMPACT OF SYSTEM OPERATION AND THE
BIOCHEMISTRY OF ENHANCED BIOLOGICAL PHOSPHORUS
REMOVAL ON THE OCCURRENCE OF ANAEROBIC STABILIZATION**

Abstract.....	154
Introduction.....	155
Materials and Methods.....	168
Results and Discussion.....	160
Conclusions.....	187
References.....	189

APPENDIX A: SYSTEM DATA FOR THE UCT SYSTEM OPERATED DURING THE COD/TP STUDY (CHAPTER II).....	192
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APPENDIX B: SYSTEM DATA FOR THE A/O, UCT 20°C AND UCT 5°C UNITS(CHAPTER III).....	198
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APPENDIX C: NMR SPECTRA OBTAINED FOR THE 20°C AND 5°C EBPR METABOLISM TESTS (CHAPTER III).....	227
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LIST OF TABLES

CHAPTER I: LITERATURE REVIEW

Table 1. Interactions between the TCA cycle intermediates and the amino acids that can be used for their replenishment	13
Table 2. Summary of the operating conditions imposed on the EBPR systems under study and the corresponding results.....	27
Table 3. COD/oxygen utilization mass balance results	44

CHAPTER II: IMPACT OF THE FEED COD/TP RATIO ON THE INTRACELLULAR STORAGE MATERIALS AND SYSTEM PERFORMANCE OF BIOLOGICAL PHOSPHORUS REMOVAL

Table 1. Summary of substrate removal and storage during the COD/TP experiments.....	61
Table 2. Observed kinetics of the intracellular storage products under different COD loadings.....	62
Table 3. Overall stoichiometry between the key parameters of the BNR system.....	62
Table 4. Intracellular storage products produced per acetate taken up (C-mol/C-mol) observed in this study and those given in other published studies.....	76

CHAPTER III: BIOCHEMISTRY OF THE ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL SYSTEMS

Table 1. Average performance values for the A/O system.....	115
Table 2. Carbon and COD equivalent of acetate, PHB&PHV and glycogen.....	117
Table 3. Carbon and phosphorus balance for the A/O system.....	118
Table 4. Average performance values for the UCT system at 20°C.....	119
Table 5. Average performance values for the UCT system at 5°C.....	120
Table 6. Table 6. Carbon and phosphorus balances for the UCT	121

system at 20°C	
Table 7. Carbon and phosphorus balances for the UCT system at 5°C.....	121
Table 8. Results of the inhibitor screening study completed as a series of batch tests performed on A/O sludge.....	123
Table 9. Enzyme assays performed on EBPR sludge samples taken on different days during operation.....	129
Table 10. The results of the enzyme activity assays.....	130
Table 11. Comparison of the anaerobic and aerobic activities of the investigated enzymes.....	132
Table 12. Distribution of the labeled carbon ($C_0=4.75\text{mM}$) between different points on the intracellular storage products at 20°C.....	135
Table 13. Distribution of the labeled carbon ($C_0=6.0\text{mM}$) between different points on the intracellular storage products 5°C.....	136

**CHAPTER IV: THE IMPACT OF SYSTEM OPERATION AND THE
BIOCHEMISTRY OF ENHANCED BIOLOGICAL PHOSPHORUS
REMOVAL ON THE OCCURRENCE OF ANAEROBIC STABILIZATION**

Table 1. COD/oxygen utilization mass balance results.....	160
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LIST OF FIGURES

CHAPTER I: LITERATURE REVIEW

Figure 1. Glycolysis pathway.....	8
Figure 2. Tricarboxylic acid cycle.....	11
Figure 3. Branched TCA cycle.....	12
Figure 4. Glyoxylate shunt.....	15
Figure 5. Succinate-Propionate Pathway.....	16
Figure 6. Propionyl-CoA production from succinyl-CoA via methylmalonyl-CoA.....	18
Figure 7. Molecular formula of glycogen.....	19
Figure 8. Molecular formulae of PHA units.....	21
Figure 9. Schematic representation of the three initial biochemical models describing the carbon flow in EBPR sludge.....	25
Figure 10. EBPR model developed by Pereira and her co-workers (1996).....	33
Figure 11. Schematic representation of the involvement of the glyoxylate bypass as suggested by Louie <i>et al.</i> (2000).....	34
Figure 12. Metabolic pathways for glycerol, sorbitol and trehalose biosynthesis	42

CHAPTER II: IMPACT OF THE FEED COD/TP RATIO ON THE INTRACELLULAR STORAGE MATERIALS AND SYSTEM PERFORMANCE OF BIOLOGICAL PHOSPHORUS REMOVAL

Figure 1. UCT type lab-scale plant operated during the study.....	59
Figure 2. Observed stoichiometry between anaerobic PHA storage and anaerobic glycogen utilization.....	63
Figure 3. Observed stoichiometry between anaerobic acetate removed and anaerobic PHA stored.....	64
Figure 4. Observed stoichiometry between anaerobic PHA storage and aerobic P-uptake.....	65
Figure 5. Observed stoichiometry between aerobic PHA utilized and aerobic glycogen replenished.....	66
Figure 6. Observed PHA concentrations through the system at steady state.....	68
Figure 7. Observed glycogen concentrations through the system at steady state.....	69
Figure 8. COD mass balance.....	70

Figure 9. Phosphorus mass balance.....	71
Figure 10. PHA mass balance.....	72
Figure 11. Glycogen mass balance.....	73
Figure 12. Average phosphate concentrations for the three periods of operation.....	74
Figure 13. Average NO ₃ -N concentration in the system.....	75

CHAPTER III: BIOCHEMISTRY OF THE ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL SYSTEMS

Figure 1. Carbon chemical shifts as dictated by the steric environment of the each individual carbon atom.....	87
Figure 2. Impact of presence of oxygen atoms in the viscosity of carbon atoms.....	87
Figure 3. Typical carbon shifts observed in carbonyls in different atomic environments.....	88
Figure 4. The locations of carbon-13 chemical shifts for different types of organic molecules.....	88
Figure 5. Chemical structures of the inhibitors that will be evaluated.....	93
Figure 6a. UCT type lab-scale plant operated during the study.....	101
Figure 6b. A/O type lab-scale plant operated during the study.....	102
Figure 7. PHA storage and utilization pattern for the A/O system.....	116
Figure 8. PO ₄ -P release and uptake pattern for the A/O system.....	116
Figure 9. Glycogen consumption and re-synthesis pattern for the A/O system.....	117
Figure 10. The response of anaerobic glycogen metabolism to varying concentrations of gluconolactone.....	125
Figure 11. The response of anaerobic phosphate metabolism to varying concentrations of gluconolactone.....	125
Figure 12. The response of aerobic glycogen metabolism to varying concentrations of gluconolactone.....	126
Figure 13. The response of aerobic phosphate metabolism to varying concentrations of gluconolactone.....	126
Figure 14. The EMP pathway that was shown to be operative in the anaerobic zones for glycogen degradation at 20°C and 5°C.....	142
Figure 15. Branched TCA cycle of EBPR sludge operating at 20°C.....	143
Figure 16. Aerobic metabolism of EBPR sludge that involves glyoxylate cycle at 20°C.....	144
Figure 17. Anaerobic metabolism of EBPR sludge operating at 5°C.....	145
Figure 18. TCA cycle proposed to be used for PHA oxidation at 5°C.....	146

**CHAPTER IV: THE IMPACT OF SYSTEM OPERATION AND THE
 BIOCHEMISTRY OF ENHANCED BIOLOGICAL PHOSPHORUS
 REMOVAL ON THE OCCURRENCE OF ANAEROBIC STABILIZATION**

Figure 1a. UCT type lab-scale plant operated during the study.....	165
Figure 1b. A/O type lab-scale plant operated during the study.....	165
Figure 2. The impact of temperature and system configuration of anaerobic stabilization.....	170
Figure 3. PHA and glycogen profiles, and anaerobic stabilization values observed during the discharge of stored poly-P in the run with the 5°C sludge brought to 20°C.....	171
Figure 4. The observed change in PHA and glycogen profiles following the discharge of stored poly-P during the run with the 5°C sludge brought to 20°C.....	172
Figure 5. The EMP pathway that was shown to be operative in the anaerobic zones for glycogen degradation at 20°C and 5°C.....	174
Figure 6. Branched TCA cycle of EBPR sludge operating at 20°C	175
Figure 7. Aerobic metabolism of EBPR sludge that involves glyoxylate cycle at 20°C.....	176
Figure 8. Anaerobic metabolism of EBPR sludge operating at 5°C.....	177
Figure 9. TCA cycle proposed to be used for PHA oxidation at 5°C.....	178

NOMENCULATURE

A/O: anaerobic/oxic.

ATP: adenosine tri phosphate.

BOD: biochemical oxygen demand.

BNR: biological nutrient removal.

CoA or CoASH: coenzyme A.

COD: chemical oxygen demand.

DO: dissolved oxygen

EBPR: excess biological phosphorus removal

ED: Entner-Doudoroff.

EMP: Embden-Meyerhoff-Parnas.

FAD: flavin adenine dinucleotide, oxidized form.

FADH₂: flavin adenine dinucleotide, reduced form.

GAO: glycogen accumulating organism.

MCRT: mean cell residence time.

MLSS: mixed liquor suspended solids.

MLVSS: mixed liquor volatile suspended solids.

NAD⁺: nicotinamide adenine dinucleotide, oxidized form.

NADH: nicotinamide adenine dinucleotide, reduced form.

NMR: nuclear magnetic resonance.

PAO: poly-phosphate accumulating organism.

Pi: orthophosphate ion.

PPi: pyrophosphate ion.

PHA: polyhydroxyalkanoates.

PHB: polyhydroxybutyrate.

PHV: polyhydroxyvalerate.

SBR: sequencing batch reactor.

SCVFA: short chain volatile fatty acids.

SRT: solids retention time.

TEM: transmission electron microscope.

TCA: tricarboxylic acid.

TP: total phosphorus

UCT: University of Cape Town.

VFA: volatile fatty acid.