

TABLE OF CONTENT – SECTION I

ABSTRACT	x
SECTION I MOVING BED BIOFILM REACTOR VERSUS BIOLOGICAL AERATED FILTRATION	XII
CHAPTER 1.0 INTRODUCTION AND BACKGROUND	1
CHAPTER 2.0 OBJECTIVES	3
CHAPTER 3.0 LITERATURE REVIEW	4
3.1 The Moving Bed Biofilm Reactor	4
3.1.1 Factors Affecting Performance	5
3.1.2 Organic carbon removal.....	10
3.1.3 Nitrification.....	10
3.2 Biological Aerated Filter (BAF)	11
3.2.1 Performance	13
3.2.2 BOD ₅ removal.....	14
3.2.3 Nitrification.....	14
3.3 Modeling Biofilm Systems	18
CHAPTER 4.0 MATERIALS AND METHODS	24
4.1 Biotreatment System Overview	24
4.2 Wastewater Characterization and modification	25
4.3 Reactor Design and Operation	26
4.3.1 MBBR.....	26
4.3.1.1 Stimulus – Response Study (Tracer Study).....	31
4.3.2 BAF.....	32
4.4 Kinetic And Stoichiometric Parameter Determination	35
4.5 Analytical methods	37
4.6 Development of the MBBR model	39
CHAPTER 5.0 RESULTS AND DISCUSSION	41
5.1 Virginia Tech Sewage Characterization	41

5.1.1	Initial Wastewater Quality Screening	41
5.2	Stimulus - Response (Tracer) Study.....	46
5.3	MBBR performance.....	49
5.3.1	BOD ₅ Removal	49
5.3.2	TSS Removal	53
5.3.3	Ammonia Oxidation.....	54
5.3.4	MBBR Performance Summary	56
5.4	Biological Aerated Filters.....	57
5.4.1	BOD ₅ removal	57
5.4.2	TSS Removal	59
5.4.3	Ammonia Oxidation.....	61
5.4.4	BAF Backwashing	62
5.4.5	BAF Performance Summary	63
5.5	MBBR Kinetic and Yield Study and Model	65
5.5.1	Biofilm thickness.	65
5.5.2	Biofilm density.....	65
5.5.3	Substrate utilization rate	66
5.5.4	Yield.....	66
5.5.5	Pseudo – analytical model and results	66
5.5.6	ISO Area Demand for MBBR versus BAF.....	67
CHAPTER 6.0	CONCLUSIONS AND RECOMMENDATIONS	68
6.1	MBBR.....	68
6.2	BAF Reactor	69
6.3	Recommendations	69
CHAPTER 7.0	REFERENCES	70
CHAPTER 8.0	APPENDICES	74
APPENDIX A1 - GENERAL	74
	BOD Supplement (‘Candy’) Preparation.....	74
	Media surface area relative to reactor volume calculation.	75
	Wastewater characteristics data	76
APPENDIX A2 - MBBR DATA	77
	MBBR BOD ₅ data.....	78
	MBBR CBOD ₅ data	79
	67 % media volume MBBR, BOD ₅ and TSS data.....	80
	MBBR SBOD ₅ data.....	81

MBBR TSS Data	82
MBBR Ammonia Data	84
APPENDIX A3 – BAF DATA.....	85
Summary of results for 1 st and 2 nd stage effluent wastewater characteristics in BAF.....	85
First column BAF TBOD ₅	86
First and Second Column BAF TBOD ₅	87
First and Second Column BAF TSS DATA.....	89
First and Second Column BAF AMMONIA DATA	91
APPENDIX A4 - BAF/ MBBR NITRATE DATA.....	92
APPENDIX A5 - KINETIC AND STOICHIOMETRIC EXPERIMENT DATA.....	93
Yield Data	93
Substrate Utilization Rate Data.....	93
SECTION II - SULFIDE-INDUCED CORROSION IN ANAEROBIC DIGESTER GAS PIPING	94
CHAPTER 1.0 INTRODUCTION AND BACKGROUND	95
1.1 Background	95
1.2 Introduction.....	97
CHAPTER 2.0 OBJECTIVES.....	98
CHAPTER 3.0 LITERATURE REVIEW.....	99
3.1 Fate of sulfur in Bioreactors	99
3.2 Corrosion mechanism.....	102
3.3 Corrosion Measurement.....	105
4.1 Reactor setup.....	106
4.2 Operation and Maintenance	111
4.3 Sample preparation and testing.....	112
4.4 Precision of Corrosion Measurement.....	114
CHAPTER 5.0 RESULTS AND DISCUSSION.....	115
5.1 Laboratory Experiment I Reactor Performance	115

5.2	Corrosion	119
5.3	Field Analysis of solid precipitate from Digester Gas Pipe at PFRWTF.....	131
CHAPTER 6.0 SUMMARY AND CONCLUSIONS.....		133
CHAPTER 7.0 RECOMMENDATIONS		133
CHAPTER 8.0 APPENDICES		134
Appendix B1	Classification of reactive environment based on H ₂ S _(g) concentration. ..	134
Appendix B2.	MLSS/ MLVSS Data.....	134
Appendix B3.	Field gas composition trends.....	136
Appendix B4.	Primary Digester Influent , Effluent Sulfate, Sulfite and Sulfide Data.	136
Appendix B4.	Primary Digester Influent , Effluent Sulfate, Sulfite and Sulfide Data.	137
Appendix B5.	pH Data.....	138
Appendix B6.	Corrosion Data.....	139
CHAPTER 9.0 REFERENCES:.....		140

TABLE OF FIGURES – SECTION I

Figure 1.1	MBBR carrier elements by Kaldnes	5
Figure 1.2(a)	Different MBBR configurations for BOD ₅ removal.....	7
Figure 1.2(b)	Different MBBR configurations for nitrification.....	8
Figure 1.3	Ideal biofilm structure as it relates to substrate penetration profile.....	19
Figure 1.4	Schematic of MBBR system with 40 % media (same configuration for 67 % media volume).....	27
Figure 1.5	Schematic of 2-stage MBBR with 40 % media volume.....	29
Figure 1.6	Schematic of MBBR with 40 % media operated with return sludge.....	30
Figure 1.7	A schematic diagram of 1 st and 2 nd stage BAF reactor.....	34
Figure 1.8	(A) Sliced MBBR media with biofilm.(B) Metric scale used to determine biofilm thickness.....	37
Figure 1.9	Single stage, 40 % media volume MBBR modeled as 3 CSTRs in series.....	39
Figure 1.10	Plot of suspended solids versus time in settling experiment on VT sewage. .	43
Figure 1.11	TBOD ₅ , CBOD ₅ and DOC trends in VT sewage.....	44
Figure 1.12	Influent TBOD ₅ and DOC correlation for VT sewage.....	45
Figure 1.13	F-Curve measured during replicate tracer experiments for a single MBBR with 40 % media volume, E-Curves derived from F- Curves.....	48
Figure 1.14	Influent and effluent BOD ₅ trends in MBBR with 40 % media volume.	49
Figure 1.15	Plot of BOD ₅ trends obtained with 67 % media volume reactors.....	51
Figure 1.16	Plot of BOD ₅ loading rate versus removal rate for 40 % media volume.....	52
Figure 1.17	Influent and effluent TSS concentration trends with 40 % media volume....	53
Figure 1.18	Ammonia trends in MBBR with 40 % media volume.....	55
Figure 1.19	BOD ₅ trends in 1 st and 2 nd stage BAF columns.....	58
Figure 1.20	Influent and 2 nd stage effluent TSS concentrations in BAF.....	60
Figure 1.21	Influent, 1 st and 2 nd stage effluent ammonia concentration in BAF	62
Figure 1.22	Plot of BOD ₅ mass loading rate versus removal rate for 1 st and 2 nd column BAFs.	64

LIST OF FIGURES – SECTION II

Figure 2.1	Mechanism of sulfide generation and corrosion in sewers.....	103
Figure 2.2.	Schematic (A) and photograph (B) of experimental setup I.....	107
Figure 2.3	Schematic (A) and photograph (B) of experimental setup II.....	108
Figure 2.4	Percentage composition of digester gas components.....	116
Figure 2.5	MLSS / MLVSS trends in primary digester effluent.....	117
Figure 2.6	pH trends in primary digester effluent.....	118
Figure 2.7	Appearance of experimental and control metals 13 days (A) and 62 (B) days after the start of the experiment.....	121
Figure 2.8	Influent sulfate concentration and effluent total dissolved sulfate, sulfite and sulfide (TDSSS).	123
Figure 2.9	Hydrogen sulfide gas concentrations in experimental and control lines during experiment II.....	124
Figure 2.10	Cumulative percentage change in weight of pipes during experiments I and II 125	
Figure 2.11	Cumulative percentage change in weight of iron shavings during experiments I and II	126
Figure 2.12	Rate of Corrosion in experimental metal iron and shaving.....	127
Figure 2.13	The percentage reduction in influent sludge sulfate concentration and total dissolved sulfate, sulfite and sulfide (TDSSS) as a fraction of influent sulfate concentration	129

LIST OF TABLES – SECTION I

Table 1.1	Typical design values for KMT reactors at 15° C ^a	8
Table 1.3	Ammonia removal using biological aerated filters for wastewater treatment ^a ..	17
Table 1.4	Kinetic parameters used in pseudo analytical model.....	20
Table 1.5	Relationship between dimensionless variables and dimensioned variables.	23
Table 1.6	Wastewater characteristics during recess periods.....	41
Table 1.7	Wastewater characteristics during school periods.	41
Table 1.8	Influent wastewater characteristics obtained during the reactor study.	46
Table 1.9	Summary of results from tracer study on a single MBBR with 40 % media volume 47	
Table 1.10	Biofilm thickness for the MBBR reactors used during the study.	65
Table 1.11	ISO Surface area demand for MBBR versus BAF.	67

LIST OF TABLES – SECTION II

Table 2.1	Free energy changes for biologically-mediated sulfate reduction and methane production.....	100
Table 2.2	Percentages of hydrogen sulfide and HS- and solubility of hydrogen sulfide as a function of pH.	101
Table 2.3	Solubility Data for Selected Metal Sulfides.....	130