

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**ACTIVATED SLUDGE TREATMENT
OF DAIRY PROCESSING WASTEWATERS:
THE ROLE OF SELECTORS FOR THE
CONTROL OF SLUDGE BULKING.**

A thesis presented in partial fulfilment of the requirements
for the degree of

Doctor of Philosophy

at
Massey University

ANNE M. LEONARD

1996

ABSTRACT

The typical wastewater from a milk processing facility producing butter and milk powder was treated in a modified activated sludge system in order to establish process characteristics and investigate operational problems.

A synthetic wastewater was developed with similar average physical and chemical characteristics to that from a full scale facility. The relative biodegradability of the wastewater fractions was assessed and basic microbial growth parameters also determined. A laboratory scale activated sludge reactor configuration was then established and its performance monitored. Although effective treatment was achieved in terms of suspended and soluble organic matter removal, the use of a completely mixed reactor resulted in the system becoming inoperable due to the excessive growth of filamentous microorganisms, with Type 0411 being the dominant filament.

In order to inhibit filamentous bulking, various selector reactor configurations were trialed. As nitrification of feed stream proteins had been indicated, unaerated selectors were used with the intention of effecting anoxic substrate removal in the initial selector zone; but due to the limited supply of oxidised nitrogen, insufficient substrate removal occurred in the selectors to prevent filamentous bulking, with Type 021N becoming dominant.

The next series of trials used aerated selectors, with some configurations demonstrating the ability to both prevent and cure filamentous bulking. The unsuccessful trials resulted in the proliferation of *Haliscomenobacter hydrossis*. From selector trials conducted it was established that the requirements for successful suppression of filamentous growth were the incorporation of an initial selector zone in which greater than 95% of removable soluble substrate was removed and the bulk solution was maintained in a fully aerobic state. Serial selector configurations demonstrated improved performance over a single selector.

From observations of the physical conditions and substrate concentrations in the reactor configurations employed, a correlation of filament type to environmental condition can be tentatively made: Types 0411 and 021N were indicated to be low organic loading type filaments, whereas *H. hydrossis* was indicated to be a low dissolved oxygen filament.

Rapid substrate removal rates were attributed to biosorption, accumulation and storage mechanisms, increasing as the selector configuration trials progressed. In general floc formers possessed a higher specific growth rate and substrate affinity than the filamentous microorganisms. Filament Type 021N was indicated to lack biosorptive capacity, however *H. hydrossis* was indicated as having a greater biosorptive capacity than the floc formers present.

The highly degradable nature of the substrate and high substrate concentration gradients imposed by the selector configuration caused rapid oxygen uptake rates; resulting in aerobic, anoxic and anaerobic substrate removal mechanisms all occurring in the initial selector zone. The occurrence of simultaneous nitrification, denitrification and phosphorus accumulation resulted in significant nutrient removals from the aerated selector reactor system, with influent nitrogen and phosphorus levels each reduced by up to 96% in the effluent stream.

This study found that an activated sludge process was an appropriate method for the effective treatment of milk processing wastewaters, as effluent suspended solids of less than 10 g.m^{-3} and soluble COD of less than 30 g.m^{-3} were consistently obtained, however a modified configuration would be required to prevent the growth of filamentous microorganisms and attendant operability problems. Due to the nature of dairy processing wastewaters, a selector reactor configuration could be employed not only to overcome potential filamentous bulking problems, but also to provide an opportunity for biological nutrient removal without the inclusion of dedicated anoxic / anaerobic reaction steps or the complex flow regimes conventionally employed for nutrient removal activated sludge systems.

ACKNOWLEDGMENTS

I wish to thank Rao Bhamidimarri and Dick Earle for providing the opportunity to do this study and also Jim Barnett and the NZ Dairy Research Institute for providing the financial support for this research.

Many thanks also to the PET laboratory and workshop staff for their assistance.

Thanks to my family and friends for moral support over the past five years: long-suffering Derek; Dad & Mum; Selma & Graham, Dave & Sue, James & Bridget et al., Dave and Jules.

Thanks to the sport of bowls for distracting Derek for long enough to allow me to finish this and the art of gardening for keeping me sane.

TABLE OF CONTENTS

	Page
Abstract	ii
Acknowledgments	iv
Table of contents	v
List of Figures	vi
List of Tables	xiii
Abbreviations and Nomenclature	xviii
Chapter 1: Introduction	1
Chapter 2: Dairy processing wastewaters and their treatment	5
Chapter 3: Methodology for the analysis of treatment system performance	35
Chapter 4: Substrate biodegradation studies	51
Chapter 5: Model activated sludge performance	91
Chapter 6: Unaerated selector reactors	127
Chapter 7: Aerated selector reactors	181
Chapter 8: Effect of influent nitrogen content	225
Chapter 9: Summary of results and discussion	285
Chapter 10: Summary and conclusions	329
Appendix: Directory of Appendix files	333
Bibliography	337

LIST OF FIGURES

	Page
Chapter 2	
Figure 2.1 Activated Sludge Process Schematic	10
Chapter 3	
Figure 3.1 'Respirometer' Vessel Schematic	46
Chapter 4	
Figure 4.1: Estimation of S_S - measurement of the OUR after substrate addition.	56
Figure 4.2: Estimation of S_S - determination of the ratio of oxygen consumed to substrate added.	56
Figure 4.3: Determination of S_S and S_H fractions from OUR data.	59
Figure 4.4: Effect of variation in S/X ratio on the interval of elevated OUR.	59
Figure 4.5: Fractionation of substrate COD by degradability and milk components.	63
Figure 4.6: Calculated biomass concentration versus time for the estimation of μ_{MAX} using the High S/X method.	66
Figure 4.7: Modified linear plot for the estimation of μ_{MAX} and K_S using the High S/X method.	67
Figure 4.8: Modified linear plot for the estimation of μ_{MAX} and K_S using the Low S/X method.	70
Figure 4.9: Use of wide range of initial substrate concentrations to determine μ_{MAX} and K_S using the Low S/X method.	74
Figure 4.10: Lactose removal rates during batch tests with varying initial lactose concentrations.	79
Figure 4.11: Effect of initial lactose concentration on removal rate in batch tests.	79
Figure 4.12: Soluble COD removal rates during batch tests at varying initial soluble COD concentrations.	81
Chapter 5	
Figure 5.1: Reactor configuration during the conventional CSTR trials.	92

Figure 5.2:	Reactor mixed liquor suspended solids concentration during the CSTR trials at various SRT.	95
Figure 5.3:	Reactor effluent quality during the 5 day SRT trial.	97
Figure 5.4:	Reactor effluent quality during the 10 day SRT trial.	98
Figure 5.5:	Reactor effluent quality during the 20 day SRT trial.	99
Figure 5.6:	Reactor effluent quality during the 30 day SRT trial.	100
Figure 5.7:	Determination of decay rate using biomass from the 10 day SRT trial, starting after 18 days at target SRT.	104
Figure 5.8:	Batch soluble COD removal rates during the various CSTR trials.	105
Figure 5.9:	Change in Sludge Volume Index during the conventional CSTR trials at various SRT.	110
Figure 5.10:	Well settling biomass. 10d SRT trial after 2 days at SRT, non-bulking SVI of 83 ml.g ⁻¹ .	113
Figure 5.11:	Filaments protruding from the flocs. 10d SRT trial after 19 days at SRT, SVI had increased to 170 ml.g ⁻¹ .	113
Figure 5.12:	Abundant filament growth. 10d SRT trial after 23 days at SRT, SVI had continued to increase to 376 ml.g ⁻¹ .	115
Figure 5.13:	Excessive filament growth. 10d SRT trial after 35 days at SRT, SVI had increased still further to 450 ml.g ⁻¹ .	115
Figure 5.14:	Dominant rotifer type observed throughout all trials.	117
Figure 5.15:	Stalked ciliated protozoa commonly observed in the CSTR trials	117
Figure 5.16:	Change in substrate removal rate and maximum specific growth rate with SVI.	123

Chapter 6

Figure 6.1:	Reactor system configuration during the selector reactor trials.	131
Figure 6.2:	Change in SVI during Trials AN1, AN2 and AN3.	135
Figure 6.3:	Change in selector soluble COD concentration with increasing recycle rate during Trial AN1.	137
Figure 6.4:	Selector soluble COD concentrations during Trial AN3.	139
Figure 6.5:	Trial AN1 after 23 days at SRT. SVI = 240 ml.g ⁻¹ .	141
Figure 6.6:	Trial AN1 after 49 days at SRT. SVI = 280 ml.g ⁻¹ .	141
Figure 6.7:	Trial AN1 after 56 days at SRT. SVI = 300 ml.g ⁻¹ .	143
Figure 6.8:	Trial AN3 after 18 days at SRT. SVI = 300 ml.g ⁻¹ .	143

Figure 6.9: Trial AN3 after 25 days at SRT. SVI unchanged from Figure 6.8.	145
Figure 6.10: Trial AN3 after 34 days at SRT. SVI unchanged from Figure 6.8.	145
Figure 6.11: Soluble COD removal and OUR during batch tests with AN2 biomass.	149
Figure 6.12: Initial soluble COD removal rates during Trials AN1, AN2 and AN3.	149
Figure 6.13: Comparison of batch soluble COD removal rates between biomass from CSTR and unaerated selector trials.	151
Figure 6.14: Soluble COD removal in aerated and unaerated batch tests during Trial AN2.	153
Figure 6.15: Ammonia concentrations in the reactor zones during Trials AN1, AN2 and AN3.	159
Figure 6.16: Plot of ammonia concentration against selector residence time during Trial AN3.	161
Figure 6.17: Nitrate concentrations in the reactor zones during Trials AN1, AN2 and AN3.	162
Figure 6.18: Nitrite concentrations in the reactor zones during Trials AN1, AN2 and AN3.	163
Figure 6.19: Phosphorus content of biomass in the reactor and selector zones during Trials AN1, AN2 and AN3.	168
Figure 6.20: Dissolved phosphorus concentration in the reactor zones during Trials AN1, AN2 and AN3.	169

Chapter 7

Figure 7.1: Aerated selector reactor system - equipment configuration.	183
Figure 7.2: Reactor soluble COD concentrations during aerated selector reactor Trials AE1 to AE4.	186
Figure 7.3: Change in Sludge Volume Index during aerated selector trials in Reactor System 2.	188
Figure 7.4: Change in Sludge Volume Index during aerated selector trials in Reactor System 1.	188
Figure 7.5: Filamentous bulking at the end of Trial AE4. SVI = 323 ml.g ⁻¹ .	191

Figure 7.6:	Reduction in filament abundance and SVI during Trial AE5; by Day 22 of the trial the SVI had decreased to 133 ml.g ⁻¹ .	191
Figure 7.7:	Soluble COD removal through the reactor system zones during Trial AE5.	193
Figure 7.8:	Soluble COD removal during batch tests using biomass from Day 29 of Trial AE5.	195
Figure 7.9:	Ammonia concentration trends during periods of Trials AE1, AE3 and AE5.	204
Figure 7.10:	Ammonia concentration trends during periods of Trials AE2 and AE4.	204
Figure 7.11:	Nitrate concentration trends during periods of Trials AE1, AE3 and AE5.	205
Figure 7.12:	Nitrate concentration trends during periods of Trials AE2 and AE4.	205
Figure 7.13:	Nitrite concentration measures during periods of Trials AE1, AE3 and AE5.	206
Figure 7.14:	Nitrite concentration trends during periods of Trials AE2 and AE4.	206
Figure 7.15:	Nitrogen content of mixed liquor solids during the various unaerated and aerated selector trials.	207
Figure 7.16:	Average ammonia concentrations in the reactor zones during the aerated selector trials.	209
Figure 7.17:	Average nitrate concentrations in the reactor zones during the aerated selector trials.	209
Figure 7.18:	Nitrogen balance during the various unaerated and aerated selector reactor trials.	211
Figure 7.19:	DRP concentration trends during periods of the trials conducted in Reactor System 2.	214
Figure 7.20:	DRP concentration trends during periods of the trials conducted in Reactor System 1.	214
Figure 7.21:	Phosphorus content of the mixed liquor solids during the aerated selector trials.	215
Figure 7.22:	Selector DRP and nitrate concentrations during the aerated selector trials.	221
Figure 7.23:	Reactor DRP and nitrate concentrations during the aerated selector trials.	222

Chapter 8

Figure 8.1:	Reactor soluble COD concentrations during Trials AE5, AE6 and AE7.	227
Figure 8.2:	Reactor soluble COD concentrations during Trial AE8.	229
Figure 8.3:	pH in the reactor zones during Trials AE6, AE7 and AE8.	231
Figure 8.4:	Change in SVI during Trials AE5, AE6 and AE7.	233
Figure 8.5:	Filament abundance on Day 2 of Trial AE7, SVI = 219 ml.g ⁻¹ .	235
Figure 8.6:	Filament abundance on Day 8 of Trial AE7, SVI = 179 ml.g ⁻¹ .	235
Figure 8.7:	Filament abundance on Day 18 of Trial AE7, SVI = 93 ml.g ⁻¹ .	237
Figure 8.8:	Filament abundance on Day 30 of Trial AE7, SVI = 63 ml.g ⁻¹ .	237
Figure 8.9:	Change in SVI during Trial AE8.	239
Figure 8.10:	Filament abundance on Day 24 of Trial AE8, SVI = 301 ml.g ⁻¹ .	239
Figure 8.11:	Filament abundance on Day 37 of Trial AE8, SVI = 183 ml.g ⁻¹ .	241
Figure 8.12:	Filament abundance on Day 40 of Trial AE8, SVI = 116 ml.g ⁻¹ .	241
Figure 8.13:	Batch soluble COD removal, Day 12 of Trial AE8.	244
Figure 8.14:	Ammonia concentration trends during the trials in Reactor System 2.	250
Figure 8.15:	Nitrate concentration trends during the trials in Reactor System 2.	251
Figure 8.16:	Nitrite concentration trends during the trials in Reactor System 2.	251
Figure 8.17:	Ammonia concentration trends during the trials in Reactor System 1.	253
Figure 8.18:	Nitrate concentration trends during the trials in Reactor System 2.	253
Figure 8.19:	Nitrite concentration trends during the trials in Reactor System 2.	254
Figure 8.20:	Average concentrations of ammonia, nitrate and nitrite during Trials AE6, AE7 and AE8, by reactor zone.	255

Figure 8.21: Average concentrations of ammonia, nitrate and nitrite in reactor zones during Trials AE6, AE7 and AE8.	255
Figure 8.22: Concentration of ammonia and nitrate flowing into and out of the first selector zone during Trials AE6, AE7 and AE8.	256
Figure 8.23: Estimation of maximum growth rate of nitrifiers from effluent nitrate and nitrite concentrations after a change in substrate N level.	259
Figure 8.24: Ammonia concentration and pH in the reactor zone during Trials AE6, AE7 and AE8.	261
Figure 8.25: Comparison of estimated nitrogen removals via denitrification during Trials AE5 to AE8.	263
Figure 8.26: Nitrogen removal balance during the trials at an increased substrate N content.	265
Figure 8.27: Effluent DRP concentrations during Trials AE6, AE7 and AE8.	267
Figure 8.28: DRP concentrations in the various reactor zones during Trials AE6, AE7 and AE8.	268
Figure 8.29: Selector A nitrate and DRP concentrations during Trials AE6, AE7 and AE8.	269
Figure 8.30: Reactor ammonia, nitrate and DRP concentrations during Trials AE6, AE7 and AE8.	269
Figure 8.31: Phosphorus content of VSS during Trials AE6, AE7 and AE8.	272
Figure 8.32: Biomass SVI, reactor pH and Selector A dissolved oxygen concentration during Trials AE6, AE7 and AE8.	275
Figure 8.33: Specific oxygen uptake rate in the various reactor zones.	279
Figure 8.34: Oxygen consumption in the various reactor zones.	279
Figure 8.35: Total mass of mixed liquor suspended solids in the reactor system during the trials in Reactor System 2.	281
Figure 8.36: Total mass of mixed liquor suspended solids in the reactor system during the trials in Reactor System 1.	281

Chapter 9

Figure 9.1: Effluent soluble COD concentrations obtained during the various trials in each reactor system.	289
Figure 9.2: Effluent suspended solids concentrations obtained during the various trials in each reactor system.	290

Figure 9.3:	Effect of floc loading in the batch tests on substrate biosorption.	292
Figure 9.4:	Effect of SVI on biosorption during batch substrate removal tests utilising biomass from unaerated selector trials.	293
Figure 9.5:	Effect of SVI on biosorption during batch substrate removal tests utilising biomass from aerated selector trials.	293
Figure 9.6:	Change in maximum Specific OUR with SVI during the various series of trials	297
Figure 9.7:	Relationship between maximum Specific OUR and K_S .	298
Figure 9.8:	Nitrogen content of biomass in the various reactor zones during the selector configuration trials.	301
Figure 9.9:	COD content of mixed liquor suspended solids in the various reactor zones during each trial.	302
Figure 9.10:	Average soluble COD concentrations observed in the various reactor configuration zones.	307
Figure 9.11:	Nitrogen compounds in the effluent stream during Trials AN1 to AE5.	311
Figure 9.12:	Reactor system nitrogen balance and trend in extent of denitrification during Trials AN1 to AE8.	315
Figure 9.13:	Trend in effluent P concentrations and the P content of biomass, during trials in Reactor System 1.	319
Figure 9.14:	Trend in effluent P concentrations and the P content of biomass, during trials in Reactor System 2.	320
Figure 9.15:	Average phosphorus content of biomass in the various reactor zones during Trials AN1 to AE8.	323
Figure 9.16:	Trend in initial selector zone DRP with increasing nitrate concentration during Trials AE5 to AE8.	324

LIST OF TABLES

Chapter 2

Table 2.1:	Dairy processing wastewater treatment methods employed in New Zealand.	9
Table 2.2:	Categorisation of filaments as proposed by Jenkins <i>et al.</i> (1993).	16

Chapter 4

Table 4.1:	Typical Effluent Characteristics of Butter and Milk Powder Production Facility.	52
Table 4.2:	Composition of Butter and Milk Powder Products.	53
Table 4.3:	Synthetic Wastewater Composition Based on Ingredient Composition.	53
Table 4.4:	Characteristics Measured on the Synthetic Wastewater.	54
Table 4.5:	Estimation of Biodegradable Fractions S_S and S_H of the Soluble Wastewater.	58
Table 4.6:	Division of Readily Biodegradable Fraction of the Wastewater into S_S and S_H .	58
Table 4.7:	Estimation of $\mu_{\max}$ and K_S Using High S/X Ratios at 20 °C.	66
Table 4.8:	Estimation of $\mu_{\max}$ and K_S Using Low S/X Ratios.	71
Table 4.9:	Effect of S/X Ratio on the Estimation of $\mu_{\max}$ and K_S at 20 °C.	73
Table 4.10:	Estimation of Y_H from batch growth tests.	76
Table 4.11:	Estimation of Y_H from Oxygen Consumption During S_S Determination.	77
Table 4.12:	Lactose Removal Rates at Varying Initial Concentrations.	80
Table 4.13:	Soluble COD Removal Rates at Varying Initial Concentrations.	82
Table 4.14:	2.5 day HRT/SRT Continuous Reactor Performance.	84

Chapter 5

Table 5.1:	Reactor mixed liquor conditions at different solids retention times.	96
Table 5.2:	Reactor effluent quality at different solids retention times.	101

Table 5.3:	Estimation of $\mu_{\max}$ and K_S for mixed liquors of various solids retention times.	102
Table 5.4:	Decay rate coefficients estimated at various solids retention times.	103
Table 5.5:	Soluble COD removal rates in batch tests using biomass at various solids retention times.	106
Table 5.6:	Effluent ammonia and nitrate concentrations at various solids retention times.	107
Table 5.7:	Reactor performance at low F/M and 20 days solids retention time.	108
Table 5.8:	Microscopic observations of filament abundance during the 10 day solids retention time trial.	111
Table 5.9:	Microscopic observations of the dominant filamentous microorganism.	112
Table 5.10:	Summary of biomass characteristics at various solids retention times and sludge volume index.	122

Chapter 6

Table 6.1:	Un aerated selector reactor treatment performance.	133
Table 6.2:	Selector performance and operation during the un aerated selector trials.	136
Table 6.3:	Microscopic observations of filament abundance during Trial AN1.	140
Table 6.4:	Soluble COD removal during aerobic batch tests.	150
Table 6.5:	Estimation of decay rate coefficient during un aerated selector trials.	154
Table 6.6:	Values Calculated for $\mu_{\max}$ and K_S during un aerated selector trials.	155
Table 6.7:	Average nitrogen and phosphorus concentrations during Trial AN1: 1 x 1.2 l selector.	156
Table 6.8:	Average nitrogen and phosphorus concentrations during Trial AN2: 1 x 2.4 l selector.	157
Table 6.9:	Average nitrogen and phosphorus concentrations during Trial AN3: 3 x 0.6 l selectors.	157
Table 6.10:	Estimation of nitrogen removal during the un aerated selector reactor trials.	165

Table 6.11:	Estimate of nitrogen removed in the settler and selector zones.	166
Table 6.12:	Phosphorus removals in the unaerated selector systems.	171
Table 6.13:	Selector soluble COD removal attributable due denitrification.	175

Chapter 7

Table 7.1:	Aerobic selector reactor treatment performance.	184
Table 7.2:	Selector performance and operation during the aerobic selector trials.	185
Table 7.3:	Batch soluble COD removal rate tests.	194
Table 7.4:	Oxygen consumption in response to substrate removal in the selector zone during Trial AE5.	196
Table 7.5:	Kinetic constants measured during aerated selector trials.	197
Table 7.6:	Mixed liquor suspended solids COD / VSS ratios.	198
Table 7.7:	DNA content of biomass at different locations in the reactor system.	199
Table 7.8:	Nitrogen and phosphorus concentrations during Trial AE1: 3x0.6 l selector configuration.	200
Table 7.9:	Nitrogen and phosphorus concentrations during Trial AE2: 1x 1.2 l selector configuration.	201
Table 7.10:	Nitrogen and phosphorus concentrations during Trial AE3: 2x 0.6 l selector configuration.	201
Table 7.11:	Nitrogen and phosphorus concentrations during Trial AE4: 1x 0.6 l selector configuration.	202
Table 7.12:	Nitrogen and phosphorus concentrations during Trial AE5: 3x 0.6 l selector configuration.	203
Table 7.13:	Nitrification rates estimated from reactor NO_2 and NO_3 concentrations.	210
Table 7.14:	Estimation of nitrogen removal during aerobic selector trials.	212
Table 7.15:	Phosphorus mass balance for the aerated selector system trials.	216
Table 7.16:	Estimation of substrate removal processes in the first selector zone.	220

Chapter 8

Table 8.1:	Treatment performance at increased substrate N content.	228
------------	---	-----

Table 8.2:	Selector performance and operation at increased substrate N content.	230
Table 8.3:	Results from batch soluble COD removal rate tests.	243
Table 8.4:	Oxygen consumption in response to soluble substrate addition.	245
Table 8.5:	Dissolved oxygen concentrations and uptake rates in the reactor system.	246
Table 8.6:	Kinetic constants determined during increased feed nitrogen content trials.	247
Table 8.7:	Biomass decay rates measured during increased substrate nitrogen content trials.	248
Table 8.8:	Nitrogen and phosphorus concentrations during Trial AE6 at 33% higher substrate nitrogen.	249
Table 8.9:	Nitrogen and phosphorus concentrations during Trial AE7: at 67% higher substrate nitrogen.	250
Table 8.10:	Nitrogen and phosphorus concentrations during Trial AE8: 67% higher substrate nitrogen.	252
Table 8.11:	Change in mass of oxidised nitrogen and ammonia through the various reactor zones during Trials AE6, AE7 and AE8.	258
Table 8.12:	Estimation of nitrification rates from reactor nitrate and nitrite concentrations.	262
Table 8.13:	Reactor system nitrogen balance during Trials AE6, AE7 and AE8.	264
Table 8.14:	Reactor system phosphorus balance during Trials AE6, AE7 and AE8.	271
Table 8.15:	Estimation of oxygen consumption for nitrification and substrate removal.	280
Chapter 9		
Table 9.1:	Summary of reactor configurations and conditions for the trials conducted.	287
Table 9.2:	Substrate removal observed in batch soluble COD removal tests.	295
Table 9.3:	Respirometric estimation of biomass kinetic parameters.	296
Table 9.4:	Trend in biomass decay rates during the study.	299
Table 9.5:	Oxygen and substrate consumption in the aerated selector zones.	304
Table 9.6:	VSS/TSS ratio of the Reactor suspended solids.	321

Appendix

Table A1	Directory of Appendix Files, Data Disk No.1	333
Table A2	Directory of Appendix Files, Data Disk No.2	335

ABBREVIATIONS AND NOMENCLATURE

AS	Activated Sludge
ATU	Allylthiourea
BOD	Biochemical Oxygen Demand (g.m^{-3})
COD	Chemical Oxygen Demand (g.m^{-3})
DO	Dissolved Oxygen (g.m^{-3})
DRI	NZ Dairy Research Institute, Palmerston North, NZ.
DRP	Dissolved Reactive Phosphorus (g.m^{-3})
EBPR	Enhanced Biological Phosphorus Removal
HRT	Hydraulic Retention Time (d)
K_S	Substrate half saturation co-efficient (g COD .m^{-3})
$\mu_{\max}$	Maximum specific growth rate (d^{-1})
N	Nitrogen
NTU	Nephelometric Turbidity Units
OUR	Oxygen Uptake Rate ($\text{g O}_2 .\text{m}^{-3} .\text{min}^{-1}$)
O_x	COD content of biomass (g COD.g TSS^{-1})
PAO	Phosphorus Accumulating Organism
P	Phosphorus
RAS	Return Activated Sludge
RBCOD	Readily Biodegradable Chemical Oxygen Demand
sCOD	Soluble COD (g COD .m^{-3}). Defined as GFC filterable COD for this study.
S	Substrate concentration (g COD .m^{-3})
S_I	Soluble Inert substrate concentration (g COD .m^{-3})
S_H	Rapidly hydrolyseable substrate (g COD .m^{-3})
S_0	Initial substrate concentration (g COD .m^{-3})
S_s	Readily biodegradable substrate (g COD .m^{-3})
SMP	Soluble Microbial Products
SpOUR	Specific Oxygen Uptake Rate ($\text{g O}_2 .\text{g VSS}^{-1} .\text{d}^{-1}$)
SRT	Solids Retention Time (d)
SVI	Sludge Volume Index (ml .g^{-1})
TKN	Total Kjeldahl Nitrogen (g .m^{-3})
TN	Total Nitrogen (g.m^{-3})
TP	Total Phosphorus (g.m^{-3})
TS	Total Solids (g.m^{-3})

TSS	Total Suspended Solids (g.m^{-3})
VSS	Volatile Suspended Solids (g.m^{-3})
X	Biomass concentration (g.m^{-3})
X_i	Particulate inert substrate concentration (g COD .m^{-3})
X_0	Initial biomass concentration (g.m^{-3})
X_s	Slowly biodegradable substrate (g COD .m^{-3})
Y	Cell growth yield ($\text{g cell mass . g substrate COD}^{-1}$)
Y_H	Heterotrophic growth yield ($\text{g cell COD . g substrate COD}^{-1}$)