

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.

**PREFERMENTATION AND SEQUENCING BATCH
REACTOR TREATMENT OF FARM DAIRY EFFLUENT
FOR BIOLOGICAL NUTRIENT REMOVAL**

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

Master of Applied Science

Massey University

Judith Mulcahy

1998

ABSTRACT

In order to meet the requirements of regional councils' Water Quality Plans implemented under the Resource Management Act (1991), many farmers in New Zealand are now irrigating effluent from farm dairy effluent. However there are situations where irrigation is not practicable and it is considered that a sequencing batch reactor (SBR) treatment system may provide a highly treated effluent able to be discharged directly to waterways.

The objectives of this research were to develop an SBR operating strategy to optimise biological nutrient removal from farm dairy effluent, monitor the effectiveness of a pilot-scale SBR at removing nitrogen and phosphorus, and assess whether the untreated effluent could be made more readily biodegradable by prefermentation.

An operating strategy was designed to enable biological nutrient removal, with the aim of achieving low phosphorus, ammonia and nitrate effluent concentrations. The SBR operating strategy is Fill, Anaerobic, Aerobic I, Anoxic, Aerobic II, Settle, and Decant.

Phosphorus is released in the anaerobic phase, using the readily biodegradable carbon. The first aerobic phase is used for nitrification and phosphorus uptake. Remaining readily biodegradable carbon is also oxidised thus the denitrification occurring in the anoxic phase depends entirely on endogenous carbon. The final aerobic phase operates as a polisher.

The results show that the SBR did not achieve biological nutrient removal: there was no apparent reduction in nitrogen and phosphorus levels in the effluent. The most likely reason for the SBR's failure to operate as expected is that it was operated on settled effluent rather than raw farm dairy effluent.

The prefermentation trial aimed to increase the readily biodegradable carbon to improve phosphorus removal. The results showed that the optimal time for prefermentation of raw farm dairy effluent at 20°C was eight to ten days, when VFA oxygen demand peaked at about 2,100 mg/L. The prefermentation trial showed a lag phase of 0 to 2 days. The VFA proportions obtained in this experiment were 1.0 : 0.3 : 0.14 : 0.08 acetic : propionic : butyric : valeric acids.

The SBR is likely to operate as part of a total treatment system, designed to enhance BNR and provide a high quality effluent. It is considered that screened farm dairy effluent would be held in a prefermentation pond with a hydraulic retention time of at least 8 to 10 days. Prefermented effluent would be treated in the SBR. The effluent would then be polished using wetlands.

KEYWORDS:

Sequencing batch reactor; prefermentation; farm dairy effluent; nitrogen removal; phosphorus removal; volatile fatty acids.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my husband, Nick, and my family and friends for their encouragement and support during my studies.

A special thanks to Ian Mason, my supervisor, for helping me throughout my research, and for always having time to see me.

I gratefully acknowledge the research funding from the FORST Technology for Business Growth scheme, and Gilbert Andrews, Fibre-Form NZ Ltd, for providing the equipment.

Many thanks to the Department of Agricultural Engineering staff and students for helping to make the year enjoyable and for offering advice, and particularly the technical staff for making things work.

Thanks are due to the Nutrition and Soil Science laboratories for the analyses they conducted, and to the Process and Environmental Technology department for the use of the PTC laboratory.

I am very grateful to Mike Boyce of Eltrol Engineering for taking care of programming the PLC for me.

Thanks, too, to the Freemasons for a scholarship which paid my fees.

TABLE OF CONTENTS

Abstract	ii
Acknowledgements	iv
Table of Contents	v
List of Figures	ix
List of Tables	xi
1. INTRODUCTION	1
1.1 NEW ZEALAND'S DAIRY INDUSTRY	1
1.2 FARM DAIRY EFFLUENT	1
1.3 ENVIRONMENTAL EFFECTS	3
1.4 LEGISLATIVE REQUIREMENTS.....	5
1.5 TREATMENT OF FARM DAIRY EFFLUENT	7
1.5.1 <i>Waste stabilisation ponds</i>	7
1.5.2 <i>Land treatment</i>	9
1.5.3 <i>Alternative treatment methods</i>	11
2. LITERATURE REVIEW.....	15
2.1 BIOLOGICAL NUTRIENT REMOVAL (BNR).....	15
2.1.1 <i>Nutrient removal processes</i>	15
2.1.2 <i>The roles of anaerobic, aerobic and anoxic phases in BNR</i>	20
2.1.3 <i>BNR in continuous flow treatment systems</i>	22
2.2 OPERATION OF SEQUENCING BATCH REACTORS (SBRs)	28
2.2.1 <i>The SBR treatment process</i>	28
2.2.2 <i>SBR operation for biological nutrient removal</i>	30

2.2.3 <i>Treatment of farm dairy effluent using an SBR</i>	33
2.3 CARBON CHARACTERISATION AND PREFERMENTATION.....	39
2.3.1 <i>Carbon characterisation</i>	39
2.3.2 <i>Prefermentation</i>	41
3. OBJECTIVES	46
4. MATERIALS AND METHODS	47
4.1 RESEARCH SITE AND PLANT	47
4.1.1 <i>Research site</i>	47
4.1.2 <i>Pilot plant</i>	47
4.2 SBR OPERATION	48
4.2.1 <i>Plant operation</i>	48
4.2.2 <i>Start-up procedure</i>	50
4.3 PROCESS DESIGN	51
4.3.1 <i>Operating strategy design</i>	51
4.3.2 <i>Calculation of treatment times</i>	54
4.3.3 <i>Summary of assumptions</i>	55
4.4 CYCLE ANALYSIS.....	56
4.5 PREFERMENTATION EXPERIMENTS	57
4.5.1 <i>Sample collection</i>	57
4.5.2 <i>Laboratory procedures</i>	58
4.6 ANALYTICAL PROCEDURES	59
4.6.1 <i>Ammonia and nitrate</i>	59
4.6.2 <i>Total Kjeldahl nitrogen and total phosphorus</i>	60
4.6.3 <i>COD</i>	60
4.6.4 <i>Suspended solids</i>	60
4.6.5 <i>Alkalinity</i>	60

4.6.6 Carbonaceous BOD.....	61
4.6.7 Volatile fatty acids (VFAs).....	61
5. RESULTS.....	63
5.1 SBR CYCLE ANALYSIS.....	63
5.1.1 Dissolved oxygen.....	63
5.1.2 Redox potential, pH and alkalinity	65
5.1.3 Nitrogen.....	67
5.1.4 Phosphorus.....	69
5.1.5 Suspended solids	69
5.1.6 COD.....	70
5.2 PREFERMENTATION	71
5.2.1 Preliminary prefermentation trial.....	71
5.2.2 Prefermentation trial.....	74
5.2.3 Prefermentation semi-continuous reactors.....	80
6. DISCUSSION.....	87
6.1 SBR OPERATION	87
6.2 PREFERMENTATION	90
6.2.1 Preliminary prefermentation trial.....	90
6.2.2 Prefermentation trial.....	91
6.2.3 Prefermentation semi-continuous reactors.....	92
6.3 IMPLICATIONS FOR FULL-SCALE SBR TREATMENT OF FARM DAIRY EFFLUENT	94
6.3.1 Process design.....	94
6.3.2 SBR treatment system	95

7. CONCLUSIONS AND RECOMMENDATIONS	98
7.1 SBR OPERATION	98
7.2 PREFERMENTATION	99
7.3 IMPLICATIONS FOR FULL-SCALE SBR TREATMENT OF FARM DAIRY EFFLUENT	101
8. REFERENCES	103
9. APPENDICES.....	112

LIST OF FIGURES

FIGURE 1.1 PHOSPHORUS STORAGES AND TRANSFERS IN THE WETLAND ENVIRONMENT ...	5
FIGURE 2.1 EFFECT OF PROCESS INFLUENT $TBOD_5$: TP RATIO ON EFFLUENT TOTAL PHOSPHORUS	20
FIGURE 2.2 SCHEMATIC DIAGRAM OF THE A^2/O PROCESS	22
FIGURE 2.3 SCHEMATIC OF THE 5-STAGE BARDENPHO PROCESS	23
FIGURE 2.4 SCHEMATIC OF THE UCT PROCESS	25
FIGURE 2.5 SCHEMATIC OF THE VIP PROCESS	26
FIGURE 2.6 EFFECT OF ANAEROBIC HYDRAULIC RETENTION TIME ON BIOLOGICAL PHOSPHORUS REMOVAL	32
FIGURE 2.7 BIOLOGICAL PATHWAYS OF METHANE FERMENTATION	42
FIGURE 4.1 PILOT PLANT LAYOUT	49
FIGURE 4.2 THEORETICAL SBR OPERATING STRATEGY FOR BNR	52
FIGURE 4.3 NITROGEN AND PHOSPHORUS REMOVAL DYNAMICS IN EACH PHASE OF SBR TREATMENT	53
FIGURE 5.1 DISSOLVED OXYGEN CONCENTRATION	64
FIGURE 5.2 REDOX POTENTIAL DURING ANAEROBIC PHASE	65
FIGURE 5.3 pH	66
FIGURE 5.4 ALKALINITY	66
FIGURE 5.5 TKN CONCENTRATION	67
FIGURE 5.6 AMMONIA CONCENTRATION	68
FIGURE 5.7 NITRATE CONCENTRATION	68
FIGURE 5.8 PHOSPHORUS CONCENTRATION	69
FIGURE 5.9 MIXED LIQUOR SUSPENDED SOLIDS	70
FIGURE 5.10 SOLUBLE COD	70
FIGURE 5.11 VFA PRODUCTION IN RAW FARM DAIRY EFFLUENT OVER 6 DAYS	71
FIGURE 5.12 BOD CURVE FOR FRESH FARM DAIRY EFFLUENT	72

FIGURE 5.13 BOD CURVE FOR FARM DAIRY EFFLUENT AFTER FERMENTATION FOR TWO DAYS.....	73
FIGURE 5.14 BOD CURVE FOR FARM DAIRY EFFLUENT AFTER FERMENTATION FOR FOUR DAYS.....	73
FIGURE 5.15 BOD CURVE FOR FARM DAIRY EFFLUENT AFTER FERMENTATION FOR SIX DAYS.....	74
FIGURE 5.16 VFA PRODUCTION IN RAW EFFLUENT.....	75
FIGURE 5.17 VFA PRODUCTION IN SETTLED EFFLUENT.....	76
FIGURE 5.18 BOD OF FRESH RAW EFFLUENT.....	77
FIGURE 5.19 BOD OF RAW EFFLUENT AFTER 10 DAYS' PREFERMENTATION.....	77
FIGURE 5.20 BOD OF RAW EFFLUENT AFTER 20 DAYS' PREFERMENTATION.....	78
FIGURE 5.21 BOD OF SETTLED EFFLUENT (DAY 0).....	78
FIGURE 5.22 BOD OF SETTLED EFFLUENT AFTER 10 DAYS' PREFERMENTATION.....	79
FIGURE 5.23 BOD OF SETTLED EFFLUENT AFTER 20 DAYS' PREFERMENTATION.....	79
FIGURE 5.24 VFA PRODUCTION IN RAW EFFLUENT (REACTOR A).....	81
FIGURE 5.25 VFA PRODUCTION IN RAW EFFLUENT (REACTOR B).....	81
FIGURE 5.26 VFA CONCENTRATIONS IN RAW EFFLUENT.....	82
FIGURE 5.27 VFA PRODUCTION IN SETTLED EFFLUENT (REACTOR A).....	83
FIGURE 5.28 VFA PRODUCTION IN SETTLED EFFLUENT (REACTOR B).....	83
FIGURE 5.29 VFA CONCENTRATIONS IN SETTLED EFFLUENT.....	84
FIGURE 5.30 VFA PRODUCTION IN SETTLED EFFLUENT WITH RAW EFFLUENT SEED (REACTOR A).....	85
FIGURE 5.31 VFA PRODUCTION IN SETTLED EFFLUENT WITH RAW EFFLUENT SEED (REACTOR B).....	85
FIGURE 5.32 INITIAL AND FINAL SOLUBLE CODs FOR EACH TREATMENT.....	86
FIGURE 6.1 FLOW DIAGRAM OF TREATMENT PROCESS.....	95
FIGURE 7.1 SBR OPERATING STRATEGY FOR BIOLOGICAL NUTRIENT REMOVAL.....	98
FIGURE 7.2 FLOW DIAGRAM OF TREATMENT PROCESS.....	102

LIST OF TABLES

TABLE 1.1 NUTRIENT CHARACTERISTICS OF RAW FARM DAIRY EFFLUENT	2
TABLE 2.1 NITRIFICATION AND DENITRIFICATION REACTION RATES FOR DOMESTIC EFFLUENT	17
TABLE 2.2 YARD EFFLUENT DATA.....	33
TABLE 4.1 THEORETICAL OPERATING STRATEGY FOR NITROGEN AND PHOSPHORUS REMOVAL	55
TABLE 4.2 EFFLUENT PRODUCTION DURING MILKING	57
TABLE 4.3 VFA MOLECULAR WEIGHTS	62