

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.

**AN INVESTIGATION OF UV DISINFECTION OF
FARM DAIRY WASTEWATER**

YONGJIAN LI

1998

AN INVESTIGATION OF UV DISINFECTION OF FARM DAIRY WASTEWATER

A thesis
submitted in partial fulfilment of the requirement
for
THE DEGREE OF MASTER OF APPLIED SCIENCE
in
NATURAL RESOURCES ENGINEERING
at
Institute of Technology and Engineering
College of Science
Massey University
Palmerston North
New Zealand

YONGJIAN LI

1998

ABSTRACT

The development of New Zealand dairy farming industry is characterised by a trend towards more intensified farming operations (larger herd sizes). This is placing greater demand for freshwater uses and effluent discharges. To comply with the microbiological standards, wastewater from farm dairies may be disinfected. Ultraviolet irradiation provides one of the best alternatives to traditional disinfection technologies.

With the development of technology and the awareness of the hazards of disinfection by-products, UV irradiation is increasingly used successfully world-wide for both drinking and wastewater disinfection. Due to the lack of data on the nature of farm dairy wastewater, no information was available on the application of UV to dairy effluents.

Wastewater samples were collected from farm dairies and analysed for characteristics relative to UV disinfection. Suspended solids (SS) contributed to nearly half the COD and 80% of the turbidity of the pond treated wastewater. Colloidal material in the 0.22 to 1.0 micron range constituted nearly 18% of the COD and 15% of the turbidity of the raw pond effluent.

Farm dairy wastewater quality changed with season. With the commencing of milking season, wastewater suspended solids, COD, and turbidity increased sharply due to the increased influent loading. However, wastewater BOD was similar over the monitoring period. With the exception of temperature and pH, wastewater quality parameters monitored showed great variation among different sites. These variations may be due to the difference in farm operation and management.

Pond treated farm dairy wastewater could not be directly disinfected by UV due to the high suspended solids (317 mg/l), COD (809 mg/l) concentration, high turbidity (450 NTU) and low UV transmittance (0%/cm). Filtration through 1.2, 0.45, and 0.22 micron filter removed all suspended solids and most of the turbidity, but UV transmittance

remained lower than 1%/cm. Alum coagulation followed by 0.45 micron filtration removed most of the colloidal material and improved UV transmittance up to 29%/cm. The dissolved organic matter was successfully removed by 0.5 g/l activated carbon (AC) adsorption following aluminium sulphate coagulation treatment. To reach 60%/cm UV transmittance, AC dose of 5 g/l was required for raw pond effluent. Bark and zeolite treatment removed ammonium from farm dairy wastewater. Bark and zeolite treatment did not greatly improve raw pond effluent UV transmittance at 254 nm. Ultracentrifugation at 10,500 g for one hour did not significantly improve UV transmission through alum coagulated farm dairy wastewater. Hydrogen peroxide was found not helpful in improving UV penetration. Strong correlation existed between UV absorbance and COD concentration. UV absorbance may be used as a parameter for estimating wastewater COD level.

Keywords: Farm dairy wastewater, ultraviolet (UV), disinfection, dilution, filtration, alum coagulation, hydrogen peroxide, activated carbon, UV transmittance.

ACKNOWLEDGEMENTS

It is a great pleasure to express my sincere thanks, heartfelt gratitude and appreciation to the following people for their contributions towards the completion of this thesis.

Firstly my supervisor Ian Mason for his invaluable guidance, encouragement, patience and constructive criticism during the completion of the project.

The Agricultural Engineering Department (especially Professor Gavin L. Wall) for providing the opportunity to study at Massey University. The professors, lecturers, secretaries, technicians for their encouragement and help.

Associated Professor Roger D. Reeves at Department of Chemistry for teaching and allowing me the use of the scanning spectrophotometer and valuable suggestions concerning the scope of the experimental work.

Associated Professor John W. Tweedie at Department of Biochemistry for helping the use of ultracentrifuge facilities and discussions about the removal of particulates from wastewaters.

Dr. Nanthi S. Bolan and Dr. David R. Scotter at Department of Soil Science for their valuable suggestions, encouragement and friendship. Dr. Bolan also supplied the bark and zeolite reagents and related information.

Mr. Dexter O. McGhie for his help in arranging laboratory instruments, reagents, and discussions about the experimental work.

All my fellow post-graduate students both in Ag-Eng building and the TVL Lab for their help and friendship.

The six farm dairies for allowing the collection of wastewater samples from their properties and supplying information about their farms.

In particular, I must express my indebtedness to my wife, Wenjuan, for her understanding, support, love and sacrifice. Finally, my son Yang is acknowledged for his understanding and all the happiness he has brought into our lives.

Above all, I present all the praises and glory to Jesus, the Christ.

TABLE OF CONTENTS

LIST OF FIGURES	xi
LIST OF TABLES	xiv
CHAPTER ONE INTRODUCTION	1
The Expanding New Zealand Dairy Farming Industry	1
The Impacts of Dairy Farming on Water Resources	1
The Need for Farm Dairy Wastewater Disinfection	2
Ultraviolet Radiation for Farm Dairy Wastewater Disinfection	3
CHAPTER TWO LITERATURE REVIEW	5
2.0 INTRODUCTION	5
2.1 HISTORICAL DEVELOPMENT	5
2.2 FUNDAMENTALS	6
2.2.1 Ultraviolet Radiation Spectra for Disinfection	6
2.2.2 UV Disinfection Mechanisms	9
2.2.3 Possible Recovery From Inactivation	12
2.2.3.1 Photoreactivation	12
2.2.3.2 Dark repair	14
2.2.3.3 The significance of repair mechanisms	14
2.3 FACTORS AFFECTING UV DISINFECTION	16
2.3.1 The Emission Spectrum of the UV Source	16
2.3.2 UV Dose for Microorganism Inactivation	18
2.3.2.1 Sensitivity of microorganisms to UV inactivation	18
2.3.2.2 UV irradiation intensity	19
2.3.2.3 Exposure duration for effective disinfection	21
2.3.2.4 UV dose requirement for wastewater disinfection	22
2.3.3 The Performance of UV Reactors	24
2.3.3.1 Current ultraviolet equipment	25
2.3.3.2 The ageing of UV lamps	29
2.3.3.3 Fouling and cleaning of UV lamp jackets	30
2.3.3.4 The hydraulic behaviour of the UV reactor	31
2.3.3.5 Estimation of the average intensity in a UV reactor	31
2.3.3.6 Predicting or modelling the reactor performance	35
2.3.4 The Quality of Wastewater for Disinfection	37
2.3.4.1 Suspended solids and turbidity	37
2.3.4.2 UV transmittance	39

2.3.4.3	Other wastewater quality parameters	41
2.3.4.4	Water quality requirement for effective UV disinfection	41
2.4	GENERAL CONSIDERATIONS IN ADOPTING UV DISINFECTION	43
2.4.1	Advantages and Disadvantages of UV Disinfection of Wastewater	43
2.4.2	Economics of UV Disinfection	44
2.4.3	System Design	45
2.5	FARM DAIRY EFFLUENT QUALITY FOR UV DISINFECTION	45
2.6	SUMMARY OF LITERATURE REVIEW	47
2.7	JUSTIFICATION AND OBJECTIVES OF THIS STUDY	49
	CHAPTER THREE MATERIALS AND METHODS	50
3.0	INTRODUCTION	50
3.1	SOURCES OF FARM DAIRY WASTEWATER	50
3.1.1	Massey No. 4 Dairy Farm	50
3.1.2	Other Dairy Farms	51
3.2	SAMPLING OF FARM DAIRY WASTEWATER	53
3.2.1	Massey No. 4 Dairy Farm	53
3.2.2	Other Dairy Farms	53
3.3	ANALYSIS OF FARM DAIRY WASTEWATER	54
3.3.1	Temperature	54
3.3.2	pH	54
3.3.3	Electrical Conductivity (EC)	55
3.3.4	Turbidity	55
3.3.5	Suspended Solids (SS)	55
3.3.6	Biological Oxygen Demand (BOD)	55
3.3.7	Chemical Oxygen Demand (COD)	56
3.3.8	UV Transmittance and Absorbance	56
3.3.9	Absorbance Spectra	57
3.4	TREATMENT OF FARM DAIRY WASTEWATER	57
3.4.1	Filtration	57
3.4.2	Dilution	57

3.4.3	Coagulation	58
3.3.4	Centrifugation	59
3.4.5	Adsorption	59
3.4.6	Oxidation	59
3.5	ANALYSIS OF EXPERIMENTAL DATA	60
CHAPTER FOUR	RESULTS	61
4.0	INTRODUCTION	61
4.1	CHARACTERISTICS OF FARM DAIRY WASTEWATERS	61
4.1.1	Wastewater from Massey No. 4 Dairy Farm	61
4.1.2	Wastewater from Other Farm Dairies	65
4.2	FARM DAIRY WASTEWATER TREATMENT	67
4.2.1	Dilution	67
4.2.2	Filtration	72
4.2.3	Coagulation Followed by Filtration	75
4.2.4	Centrifugation	81
4.2.5	Adsorption	81
4.2.6	Oxidation	86
4.3	WASTEWATER ABSORBANCE SPECTRA	87
4.3.1	Absorbance Spectra of Raw and Filtered Pond Effluent	87
4.3.2	Absorbance Spectra of Raw and Coagulated-Filtered Pond Effluent	88
4.3.3	Absorbance Spectra of Raw and Carbon Adsorbed Pond Effluent	89
4.3.3.1	Absorbance spectra of alum coagulated and carbon adsorbed wastewaters	89
4.3.3.2	Absorbance spectra of raw and carbon treated pond effluent	91
4.3.4	Absorbance Spectra of Wastewaters Treated by Bark and Zeolite	92
4.3.5	Summary of the Absorbance Spectra	93
CHAPTER FIVE	DISCUSSION	95
5.0	INTRODUCTION	95
5.1	CHARACTERISTICS OF POND TREATED FARM DAIRY WASTEWATERS	95

5.1.1	Seasonal Variability of Farm Dairy Wastewaters	95
5.1.2	Site Differences of Farm Dairy Wastewaters	96
5.1.3	Feasibility of UV Disinfection of Raw Farm Dairy Wastewater	97
5.1.4	Trend in Farm Dairy Pond Effluent Quality	97
5.2	CHARACTERISTICS OF FARM DAIRY WASTEWATER AFTER TREATMENT	98
5.2.1	Dilution Treatment	98
5.2.2	Filtration Treatment	99
5.2.3	Coagulation Followed by (0.45 µm) Filtration	100
5.2.4	Ultracentrifugation	103
5.2.5	Oxidation by Hydrogen Peroxide	104
5.2.6	Adsorption	104
5.2.6.1	Activated carbon (AC) treatment	104
5.2.6.2	Bark treatment	105
5.2.6.3	Zeolite treatment	105
5.2.6.4	Reaction time and dose in adsorption treatment	106
5.3	ABSORBANCE SPECTRA OF WASTEWATERS	106
5.3.1	Raw Farm Dairy Wastewaters	106
5.3.2	Aluminium Sulphate Coagulated Farm Dairy Wastewaters	107
5.3.3	Activated Carbon (AC) Treated Farm Dairy Wastewaters	107
5.3.4	Bark and Zeolite Treated Farm Dairy Wastewaters	107
5.4	RESEARCH LIMITATION AND FURTHER RESEARCH	110
	CHAPTER SIX CONCLUSIONS	111
	REFERENCES	114
	APPENDICES	121 - 141

LIST OF FIGURES

Figure 1-1	Trends in herd number and size in New Zealand (LIC, 1997)	2
Figure 2-1	Electromagnetic spectrum (adapted from Stover <i>et al.</i> , 1986)	7
Figure 2-2	Relative germicidal effectiveness as a function of wavelength (Oda, 1969)	9
Figure 2-3	Relative abiotic effects of UV on <i>E. coli</i> compared to relative absorption of ribose nucleic acid (Loofbourow, 1948)	10
Figure 2-4	Examples of DNA and UV damage to DNA (Stover <i>et al.</i> , 1986)	11
Figure 2-5	Hypothesized photoreactivation reaction mechanism (Harm, 1975, and Lindenauer and Darby, 1994)	13
Figure 2-6	Radiant power output spectra from (a) low-pressure and (b) medium-pressure mercury arc (Meulemans, 1987)	17
Figure 2-7	Schematic illustration of open-channel ultraviolet disinfection system. Top, horizontal lamp configuration; bottom, vertical lamp configuration (Bierck <i>et al.</i> , 1986).	27
Figure 2-8	Typical ultraviolet lamp output as a function of time (Bierck <i>et al.</i> , 1996)	29
Figure 2-9	Lamp geometry for point source summation (PSS) approximation of intensity (adapted from Stover <i>et al.</i> , 1986)	34
Figure 2-10	Effect of particulates on UV disinfection efficiency	38
Figure 4-1	Changes in pond effluent quality over the monitoring period	62
Figure 4-2	BOD of pond treated wastewaters from Massey No. 4 Dairy Farm	63
Figure 4-3	Measured and predicted BOD of pond effluent from Massey No. 4 Farm Dairy (combined data sets)	64
Figure 4-4	Pond treated farm dairy wastewater BOD	66
Figure 4-5	Wastewater UV transmittance effected by dilution	67

Figure 4-6	UV Absorbance as a function of dilution	68
Figure 4-7	Effect of dilution on Wastewater UV absorbance	70
Figure 4-8	Effect of dilution on wastewater COD	71
Figure 4-9	Effect of dilution on wastewater turbidity	71
Figure 4-10	Effect of filtration on wastewater quality	73
Figure 4-11	Wastewater turbidity as function of filtration and dilution	74
Figure 4-12	Wastewater COD as function of filtration and dilution	76
Figure 4-13	Wastewater COD and turbidity as function of UV absorbance with dilution and filtration treatment	76
Figure 4-14	UV transmittance of pond treated wastewater after alum coagulation followed by 0.45 micron filtration	77
Figure 4-15	Effect of stirring and settling time on UV transmission	78
Figure 4-16	Effect of settling time on UV transmission through wastewaters	79
Figure 4-17	Relationship between turbidity and UV absorbance after 200 - 1600 mg/l alum coagulation treatment	80
Figure 4-18	Relationship between turbidity and COD after alum coagulation treatment	80
Figure 4-19	UV transmittance of alum coagulated wastewater before and after ultracentrifugation treatment	82
Figure 4-20	UV transmittance of wastewater after activated carbon adsorption treatment	83
Figure 4-21	UV transmittance of wastewater affected by bark adsorption treatment	84
Figure 4-22	UV transmittance of wastewater affected by zeolite adsorption treatment	84
Figure 4-23	Effect of activated carbon dose and reaction time	85
Figure 4-24	Effect of hydrogen peroxide dose and reaction time	86

Figure 4-25	Absorbance reduction of pond treated wastewaters after filtration treatment	88
Figure 4-26	Absorbance reduction of pond treated wastewaters after alum coagulation and 0.45 micron filtration treatment	89
Figure 4-27	Absorbance reduction of 1600 mg/l alum coagulated wastewaters after activated carbon (AC) treatment	90
Figure 4-28	Absorbance reduction in pond treated effluent after activated carbon (AC) treatment	92
Figure 4-29	Absorbance reduction in pond treated wastewaters after bark and zeolite treatment	93
Figure 5-1	Absorbance spectra of (15 mg/l) nitrate and (95 mg/l) ammonium as well as the combined spectrum by (15 mg/l) nitrate and (95 mg/l) ammonium	109

LIST OF TABLES

Table 2-1	Bond energy of importance in microbiological systems (March, 1985)	8
Table 2-2	Approximate dose requirement to achieve a survival ratio of 0.1 at 253.7 nm (Meulemans, 1987)	19
Table 2-3	Water quality parameter values reported for effective UV disinfection	42
Table 2-4.	Summary of effluent characteristics for domestic sewage oxidation ponds and dairy shed oxidation ponds (adopted from Hickey <i>et al.</i> , 1989a and 1989b)	46
Table 4-1	Characteristics of pond treated wastewater from Massey No. 4 Dairy Farm	61
Table 4-2	Biochemical oxygen demand (BOD) properties of pond treated wastewater from Massey No. 4 Dairy Farm (calculated by the Fujimoto Method, Metcalf & Eddy, 1991)	63
Table 4-3	Correlation coefficient (R) of the BOD data sets for Massey No. 4 Dairy Farm pond effluent	64
Table 4-4	Quality parameters of pond effluents from Massey No. 4 and six other farm dairies	65
Table 4-5	Correlation coefficient (R) between dilutions (a) UV absorbance (b) COD (c) Turbidity	69
Table 4-6	Characteristics of raw and filtered wastewater from Massey No. 4 Dairy Farm pond	72
Table 4-7	Coagulation effectiveness by (773 mg/l) alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$) and (1000 mg/l) zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$) solution	77
Table 4-8	Correlation coefficient (R) among alum dose, turbidity, UV absorbance and COD	80
Table 4-9	Grouping of absorbance spectra (200 - 800 nm) of wastewaters coagulated by 1600 mg/l alum and treated by activated carbon (AC) adsorption.	91

Table 4-10	Grouping of absorbance spectra (200 - 800 nm) of pond treated wastewaters treated by activated carbon (AC) adsorption	91
------------	---	----