UNIVERSITI PUTRA MALAYSIA

ANOXIC-AEROBIC STABILIZATION OF SETTLED ACTIVATED SLUDGE FROM A SEW AGE TREATMENT PLANT

HII SIEW LING

FK 2001 50

ANOXIC-AEROBIC STABILIZATION OF SETTLED ACTIVATED SLUDGE FROM A SEWAGE TREATMENT PLANT

HII SIEW LING

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

2001

ANOXIC-AEROBIC STABILIZATION OF SETTLED SEWAGE SLUDGE FROM A SEWAGE TREATMENT PLANT

By

H[redacted] SIEW LING

Thesis Submitted in Fulfilment of the Requirement for the Degree of Master of Science in the Faculty of Engineering Universiti Putra Malaysia

August 2001

DEDICATION

Especially dedicated to my dearest:-

grandmothers ah Po and yea Ma,

father ah Ba, mother ah Máh,

brother Ming, brother Ping,

sister ah Chen, sister ah Fei.

Will never ever let you all down !

"In dealing with the environment, we must learn not how to master the nature but how to master ourselves, our institutions, and our technology."

Richard M. Nixon,
Message to Congress of the United States of America
On release of Environmental Quality:
The First Annual Report of the Council
On Environmental Quality, 1970.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

ANOXIC-AEROBIC STABILIZATION OF SETTLED ACTIVATED SLUDGE FROM A SEWAGE TREATMENT PLANT

By

HII SIEW LING

August 2001

Chairman: Fakhru'l-Razi Ahmadun, Ph.D.

Faculty: Engineering

Conventional aerobic sludge stabilization is a power-intensive process. Another major upset is the resulting drop in mixed liquor pH (MLpH). Furthermore, the high concentration of ammonical nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N) and ortho-phosphate (PO_4-P) in the filtrate, could be a strong water-polluting agent. In this study, the anoxic-aerobic stabilization system incorporates, at regular intervals, non-aerated periods during aerobic stabilization. Four different stabilization modes (anoxic-aerobic, anoxic-aerobic with methanol, aerobic with lime control and aerobic) were applied to remove both the mixed liquor volatile suspended solids (MLVSS) and soluble nutrients simultaneously. Both the anoxic-aerobic systems were found to have higher solids decay rate, i.e., 0.064 day^{-1} and 0.057 day^{-1}, respectively, as compared with lime-controlled (0.049 day^{-1}) and aerobic systems (0.033 day^{-1}). Anoxic-aerobic stabilization also maintained neutral MLpH levels at 'no cost', which is superior to daily lime dosing. The unfavorable environment within the aerobic digester (pH 5.51 – pH 6.59) is believed to retard the endogenous metabolisms of the sludge. The aerobic digester showed a significantly high build-up of NH_4-N (95% higher) but lower

concentrations in both anoxic-aerobic and lime-controlled systems. Since both the anoxic-aerobic digesters experienced anoxic conditions on a regular basis, the peak nitrate were much lower (2.6 mg/L in anoxic-aerobic digester and 1.4 mg/L in anoxic-aerobic digester with methanol). The addition of methanol did accelerate the denitrification process. In contrast, nitrate levels in the lime-controlled digester and aerobic digester were greater than 30.0 mg/L, which do not comply with the World Health Organization standards. Since PO_4-P is not lost from the digester as gas, the concentration in the four digesters increased with digestion time. The lowest PO_4-P levels in the lime-controlled digester could be a function of calcium phosphate formation. In contrast, the highest level of PO_4-P in the fully aerobic digester was due to the low MLpH. Alkalinity was consumed and produced during the anoxic-aerobic stabilization process, thus, there was no net change in the alkalinity level.

The experimental results indicate that the anoxic-aerobic digestion system is definitely a suitable method for the stabilization of sludge, in terms of solids reduction and soluble nutrients removal.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENSTABILAN ANOXIK-AEROBIK UNTUK MENDAPAN ENAPCEMAR TERAKTIF DARIPADA SATU LOJI RAWATAN NAJIS TEMPATAN

Oleh

HII SIEW LING

Ogos 2001

Pengerusi: **Fakhru'l-Razi Ahmadun, Ph.D.**

Fakulti: **Kejuruteraan**

Penstabilan enapcemar dengan cara aerobik lama berbekalkan tenaga yang banyak. Selain itu, ia juga menyebabkan kejatuhan pH cecair. Tambahan lagi, kepekatan ammonia (NH_4-N), nitrat (NO_3-N), nitrik (NO_2-N) dan orto-fosfat (PO_4-P) yang tinggi dalam cecair tersaring adalah agen pencemaran yang bahaya. Dalam penyelidikan ini, penstabilan enapcemar secara anoxik-aerobik melibatkan, pada sesetengah masa, tiada bekalan udara semasa penstabilan dijalankan. Empat cara penstabila (anoxik-aerobik, anoxik-aerobik dengan tambahan metanol, aerobik dengan kawalan pH dan aerobik) telah direkabentukkan untuk menyingkirkan pepejal terampai mudah mengewap (MLVSS) dan nutrien mudah larut secara serentak. Kedua-dua sistem anoxik-aerobik menunjukkan kadar pereputan pepejal enapcemar yang lebih tinggi, iaitu, masing-masing 0.064 $hari^{-1}$ dan 0.057 $hari^{-1}$, berbanding dengan sistem aerobik dengan kawalan pH (0.049 $hari^{-1}$) dan sistem aerobik (0.033 $hari^{-1}$). Penstabilan anoxik-aerobik juga didapati berupaya mengekalkan pH cecair pada tahap neutral, iaitu jauh lebih baik daripada pengawalan melalui tambahan kalsium hidroksida. Keadaan berasid dalam reaktor

aerobik (pH 5.51 – pH 6.59) dipercayai menghalang metabolisma endogenos enapcemar tersebut. Reaktor aerobik menunjukkan pengumpulan NH_4-N yang banyak (95% lebih) tetapi kepekatan yang rendah didapati di dalam kedua-dua reaktor anoxik-aerobik dan reaktor dengan kawalan pH. Memandangkan keadaan anoxik dialami oleh kedua-dua reaktor anoxik-aerobik semasa penstabilan dijalankan, kepekatan maksimum nitrat adalah jauh lebih rendah (2.6 mg.L dalam reaktor anoxik-aerobik dan 1.4 mg/L dalam reaktor anoxik-aerobik dengan tambahan metanol). Penambahan metanol memang dapat mempercepatkan proses denitrifikasi. Sebaliknya, kepekatan nitrat dalam reaktor aerobik kawalan pH dan reaktor aerobik adalah lebih daripada 30.0 mg/L. Memandangkan PO_4-P tidak disingkirkan dari reaktor sebagai gas, kepekatannya dalam keempat-empat reaktor meningkat dengan masa. Kepekatan terendah PO_4-P dalam reaktor aerobik kawalan pH adalah satu fungsi pembentukan kalsium fosfat. Sebaliknya, kepekatan tertinggi PO4-P dalam reaktor aerobik adalah disebabkan pH yang rendah. Kealkalian diguna dan dihasilkan semula semasa proses penstabilan anoxik-aerobik, maka, tiada perubahan bersih dalam kandungan kealkalian.

Keputusan esperimen menunjukkan penstabilan anoxik-aerobik memang adalah satu cara yang sesuai untuk menstabilkan enapcemar, samaada dari segi pengurangan pepejal enapcemar ataupun penyingkiran nutrien terlarut.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my heartfelt appreciation and gratitude to my chairman, Dr. Fakhru'l-Razi Ahmadun for constantly guiding and encouraging me during the many *crisis* in this study. Special thanks also to the panel of supervisory committee, Mr. Abdul Ghani Liew Abdullah and Associate Professor Dr. Saari Mustapha, for their time and energy spent in making this a better work.

My appreciation to the Miss Maslinda Abdullah of the Environmental Engineering Laboratory for her assistance and technical support throughout this study. To the staffs in Engineering Faculty, I wish to express my sincere thanks for being so kind in helping me in many ways to complete this study

Special thanks to Dr. Wesley, Dr. Phong, Yun Kit, Chin Ming, Ming Ying, and all my friends who helped ensure the success of this project – great work!

Last but not least, utmost thanks to my beloved Dad, Mum, Ming, Chen, Fei and Ping for their love, understanding, sacrifices and steadfast support in making this struggle turns reality. May all being be well and happy. With all my love, a "BIG" thank you!

TABLE OF CONTENTS

		Page
DEDICATION		ii
ABSTRACT		iii
ABSTRAK		v
ACKNOWLEDGEMENTS		vii
APPROVAL		viii
DECLARATIONS		x
LIST OF TABLES		xiii
LIST OF FIGURES		xiv
LIST OF ABBREVIATIONS		xvi
CHAPTER		
I	**INTRODUCTION**	1
	Objectives of the Study	5
	Significant of the Study	5
	Scope of the Study	5
II	**LITERATURE REVIEW**	7
	Sewerage System Development in Malaysia	7
	Historical Background	8
	Pre-privatization	9
	The Solution	11
	Present Sewerage Systems and Issues	11
	Malaysia's Sewerage Standards and Water Quality Management	12
	Current Sludge Issues	13
	Sewage Sludge Treatment	14
	Properties of Sewage Sludge	16
	Physical Properties	16
	Chemical Properties	17
	Biological Properties	22
	Nitrogen Mineralization of Sewage Sludge	25
	Importance of Sewage Sludge	26
	Sludge Stabilization	27
	Defining Sludge (Biosolids) Stability	27
	Approaches to Define Stability	28
	Problems with Fully Aerobic Process	30
	Development of Anoxic-Aerobic Sludge Digestion Process	33
	Process Theory	35
	Aerobic Phase	36
	Anoxic Phase	38
	Methanol as An External Carbon Source	40
	Nitrogen Transformation	42

	Phosphorus Transformatin	42
	Merits of Anoxic-Aerobic Digestion	43
	Demerits of Anoxic-Aerobic Digestion	45
	Solids Reduction: First-Order Biochemical Reaction	45
III	**METHODOLOGY**	48
	Sludge Sample	48
	Operating Procedure	48
	Experimental Design	52
	Laboratory Analysis	53
	Sludge Solids	53
	Supernatant	57
IV	**RESULTS AND DISCUSSIONS**	62
	Digestion Kinetics	63
	Decomposition of Sludge Solids	63
	Endogenous Decay Coefficients	71
	Comparison with Other Anoxic-Aerobic Digesters	75
	Supernatant Characteristics	77
	Mixed-liquor pH	77
	Ammonical Nitrogen Levels	84
	Nitrate Nitrogen Levels	89
	Nitrite Nitrogen Levels	93
	Ortho-phosphate Levels	94
	Alkalinity Consumption and Production	99
V	**CONCLUSIONS**	102
	Conclusions	102
	Recommendations	105
REFERENCES		106
APPENDICES		112
BIODATA OF THE AUTHOR		157

LIST OF TABLES

Table		Page
2.1	Physical Characteristics of Sludge	17
2.2	Sludge Characteristics in MWWTP Serving Different Catchment Types	21
2.3	Sewage Sludge Properties	24
3.1	Sample Analysis Parameters and Methods	61
4.1	Average Values of MLVSS Concentration and Percent MLVSS Reduction for 4 Different Digestion Modes	65
4.2	Summary of MLVSS Conditions After 18 days of Digestion	69
4.3	Percentage of MLVSS Reduction per Unit of Air Supplied	70
4.4	Determination of Kinetic Coefficients in 4 Different Digestion Modes	73
4.5	Summary of the Endogenous Decay Coefficients	71
4.6	Some of the Recent Reviewed Research on Anoxic-Aerobic Sludge Digestion	76
4.7	Comparison between Percentage of MLVSS Reduction and Average MLpH Levels	81
4.8	Comparison of 4 Digesters' Ammonical Nitrogen Concentration With World Health Organization Standard	85
4.9	Comparison of 4 Digesters' Nitrate Nitrogen Concentration With World Health Organization Standard	90

LIST OF FIGURES

Figure		Page
2.1	Sludge Treatment Process	15
2.2	Decomposition Chain of Proteinaceous Compound	19
2.3	Basic Reaction of Aerobic Sludge Digestion	35
2.4	An Example on Determination of Decay Coefficient	47
3.1	Schematic Layout of Taman Sri Nading Sewage Treatment Plant	51
3.2	Experimental Design	52
3.3	Procedures Involved In Determining MLSS	55
3.4	Procedures Involved In Determining MLVSS	56
4.1	Average Values of MLSS Remained During Various Types of Digestion Modes	66
4.2	Decrease in the MLVSS Component During Various Types of Digestion Modes	67
4.3	Percent MLVSS Reduction (%) vs Digestion Time	68
4.4	ln (S_t/S_o) vs Digestion time	74
4.5	Daily MLpH Levels for Run 1	78
4.6	Daily MLpH Levels for Run 2	79
4.7	Daily MLpH Levels for Run 3	80
4.8	Average Supernatant Ammonical Nitrogen Levels	87
4.9	Fate of Various Nitrogen Forms During Aerobic Sludge Digestion with pH Control	88

4.10 Average Supernatant Nitrate and Nitrite Nitrogen Levels 91

4.11 Variation of Supernatant Ortho-phosphate Levels 95

4.12 Relationship Between Ortho-phosphate Release and MLpH Within Digester D for Run 2 97

4.13 Alkalinity Consumption and Production Over Two Single Cycle Within Digester A (Anoxic-Aerobic) 101

LIST OF ABBREVIATIONS

MLpH	Mixed Liquor pH
NH_4-N	Ammonical Nitrogen
NO_3-N	Nitrate Nitrogen
NO_2-N	Nitrite Nitrogen
PO_4-P	Ortho-phosphate
MLSS	Mixed-Liquor Suspended Solids
MLVSS	Mixed-Liquor Volatile Suspended Solids
day^{-1}	Per Day
mg/L	Milligram Per Liter
CO_2	Carbon Dioxide
H_2O	Water
ENR	Endogenous Nitrate Respiration
N_2	Nitrogen Gas
RM	Ringgit Malaysia
EQA	Environmental Quality Act
MS1228	Code of Practice for Design and Installation of Sewerage Systems 1981
NGDWQ	Nasional Guidelines for Drinking Water Quality
MOH	Ministry of Health
WHO	World Health Organization
MWWTP	Municipal WasteWater Treatment Plant
TKN	Total Kjehdal Nitrogen
P	Phosphorus
P_2O_5	Phosphate
VS	Volatile Solids
VSS	Volatile Suspended Solids
O_2	Oxygen
NH_4^+	Ammonium Ion
NO_3^-	Nitrate Ion
NO_2^-	Nitrite Ion

$C_2H_7NO_2$	Cell Mass of a Microorganism
SRT	Solid Retention Time
T	Temperature
NaOH	Sodium Hydroxide
$Ca_3(PO_4)$	Calcium Phosphate
$CaCO_3$	Calcium Carbonate
NH_4HCO_3	Ammonia Bicarbonate
H^+	Hydrogen Ion
OH^-	Hydroxide Ion
DO	Dissolved Oxygen
NO	Nitric Oxide
N_2O	Nitrous Oxide
CH_3OH	Methanol
e^-	electron
PO_4^{2-}	Phosphate Ion
exp	Exponential
ln	Natural Logarithm
$Ca(OH)_2$	Calcium Hydroxide (Lime)
∅	Diameter
rpm	Rotation Per Minute

CHAPTER 1

INTRODUCTION

Sewage sludge is an unavoidable waste product from the wastewater treatment processes. The increasing number of wastewater emitters who are connected to the municipal wastewater treatment plants as well as the ongoing extension of sewage plants for improvement of clarification leads to an increasing amount of sewage sludge.

Sewage sludge, in its raw state, is putrescible and rapidly develops strong and offensive odours. It is not surprising, therefore, that the most common environmental problem it causes is smell nuisance (Tchobanoglous and Burton, 1991). Due to this problem and avoid public complaints that, over the past 80 years or so, various methods for controlling the putrescibility and malodorous of sludges have been brought into operation at sewage works. These methods essentially comprise various forms of anaerobic and aerobic digestion, lime addition, certain other chemical treatments or, for dewatered sludge, a range of composting techniques. Up to 65% of the wastewater treatment operating costs are in the preparation for stabilization of and disposal of sewage sludge (Gray, 1989). It is thus becoming urgent and necessary to establish a suitable protocol to deal with the fate of such products.

Sludge are stabilized to (1) reduce pathogens, (2) eliminate offensive odors, and (3) inhibit, reduce, or eliminate the potential for putrefaction. Survival of pathogens, release of odors, and putrefaction occur when microorganisms are allowed to flourish in the organic fraction of the sludge. The means to eliminate these nuisance conditions through stabilization are (1) the biological reduction of volatile content, (2) the chemical oxidation of volatile matter, (3) the addition of chemicals to the sludge to render it unsuitable for survival microorganism, and (4) the application of heat to disinfect or sterilize the sludge (Tchobanoglous and Burton, 1991; Michael *et al.*, 1997).

Traditionally, sewage sludge is biologically stabilized by either aerobic or anaerobic digestion. Aerobic stabilization is widely used to treat waste activated sludge. Although the retention time of aerobic digestion is shorter than that of anaerobic digestion, it can achieve the same efficiency in the reduction of sludge volume as that of the anaerobic digestion. Furthermore, it produces an odorless and stable sludge.

Aerobic stabilization generally less expensive. It is also simpler operationally and is sometimes not even a separate process. The aerobically digested sludge can be used for land reclamation and as fertilizer for agricultural purposes.

However, typical well-documented problems associated with the fully aerobic digestion process include high energy costs, i.e., it is a power-intensive process (because of power requirements for oxygen transfer) compared to anaerobic digestion (Akira *et al.*, 1988; Jenkins and Mavinic, 1989a; Hao and Kim, 1990; Tchobanoglous and Burton, 1991; Albertson *et al.*, 1995, Michael *et al.*, 1997).

One of the major drawbacks to fully aerobic digestion is the resulting drop in mixed liquor pH (MLpH). The pH levels as low as 3.8 have been reported in the literature (Jenkins and Mavinic, 1989b). The low pH conditions will decrease the solids reduction process (Anderson and Mavinic, 1984, Jenkins and Mavinic, 1989a). Furthermore, the supernatant and filtrate from the digestion system could be a strong water-polluting agent because they still contain high concentration of nutrient salts. Consequently, the need is apparent for other biological alternatives to stabilize sewage sludge.

The concept of anoxic-aerobic sludge digestion incorporates, at regular intervals, non-aerated periods during aerobic digestion, appears to be one such promising alternatives. This produces a digester, which cycles between anoxic and aerobic conditions. Theoretically, under aerobic digestion conditions, the microorganisms consume their own protoplasm to obtain energy for cell maintenance. As a result, the carbonaceous portion of sludge is oxidized aerobically to carbon dioxide (CO_2) and water (H_2O), and the nitrogenous compounds are oxidized to ammonia and nitrate. The removal of nitrogen in the form of nitrate by conversion to nitrogen gas can be accomplished biologically under anoxic (without oxygen) conditions. Anoxic sludge digestion through endogenous nitrate respiration (ENR) is similar to aerobic digestion, except that nitrate is used to support endogenous respiration.

Anoxic-aerobic sludge digestion would significantly reduce power costs over aerobic digestion, because only mixing would be required in the anoxic mode. Stabilization through anoxic sludge digestion also reduces nutrient loads, because the total nitrogen load from the digestion supernatant, which must be returned to the main wastewater treatment process, would be reduced because of nitrogen gas (N_2) lose. Due to nitrification-denitrification cycling, a neutral pH was maintained inside the tank, thus negating the need for chemical (e.g., lime) addition. Hence, the higher decay rate of biomass under optimum pH may achieve. Consequently, this could result in better-digested sludge characteristics and supernatant quality.

Objectives of the Study

In this study, there are two main objectives to achieve, which are stated as below:

1. To observe the solids destruction and soluble nutrients removal through the anoxic-aerobic system.
2. To assess the acceptability of anoxic-aerobic digestion, in comparison to fully aerobic digestion with or without pH control.

Significant of the Study

The results and findings of this study can be used as a base line data for the further research. At the same time, the data can be applied to the design and development of an efficient anoxic-aerobic sewage sludge stabilization system for the facility being studied.

Scope of the Study

The scope of this study was limited to the following items:

1. Destruction of solids was assumed to take place only within the biodegradable or volatile content of the sludge.
2. Nutrients removal only included soluble and inorganic component of nutrient. Organic nutrients removal was excluded. Hence, total nutrient removal could not be detected.

3. Detail costing for the power and energy consumptions were not be a part of the study.
4. Only bench-scale digesters were used.