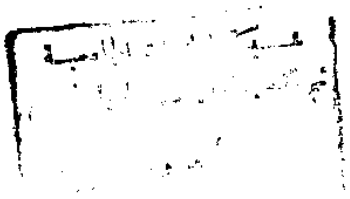
AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT



The Anaerobic Treatment Of Complex Wastewater

By

Mohamed Aly Ahmed Fergala

Assistant Lecturer in Public Works Section
Civil Engineering Department
Faculty of Engineering
Ain Shams University

1995

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT

The Anaerobic Treatment Of Complex Wastewater

A Thesis Submitted in Partial Fulfilment for
The Requirements of The Degree of

DOCTOR OF PHILOSOPHY

in

CIVIL ENGINEERING

By

Mohamed Aly Ahmed Fergala

Assistant Lecturer in Public Works Section
Civil Engineering Department
Faculty of Engineering
Ain Shams University

Under The Cooperative Supervision of :-

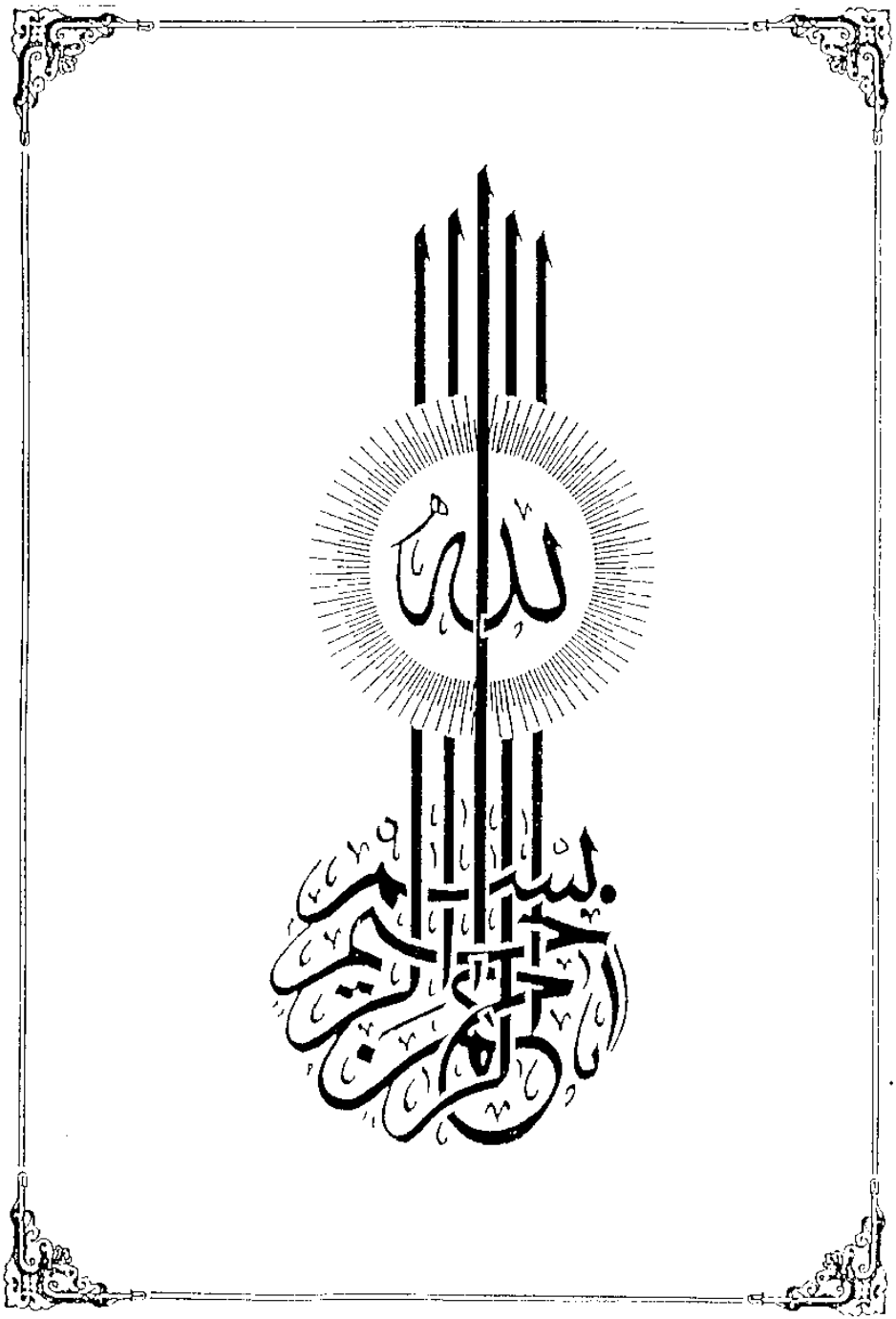
Dr.ir. : S.KJ. Sayed

Head of Department Water Pollution Control
Van Hall Institute
Groningen, The Netherlands (Holland).

Prof.Dr. : H.I. Ali

Professor of Sanitary Engineering
Civil Engineering Department
Faculty of Engineering
Ain Shams University
Cairo, Egypt.

1995



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT

STATEMENT

This dissertation is submitted to "Ain Shams Unversity" for the degree of "Doctor of Philosophy in Civil Engineering".

The work included in this dissertation was carried out during the period from 1991 to 1995 under "The Channel System" between The Public Works Department, Faculty of Engineering, Ain Shams University in Egypt and The Department of Water Pollution Control, Van Hall Institute in The Netherlands (Holland).

No part of this dissertation has been submitted for a degree or qualification at any university or institution.

Name : Mohamed Aly Ahmed Fergala

Signature : M. Fergaly

Date : 2/9/95

1995

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEERING DEPARTMENT

APPROVAL SHEET

The Anaerobic Treatment Of Complex Wastewater

A Thesis Submitted in Partial Fulfilment for
The Requirements of The Degree of

DOCTOR OF PHILOSOPHY

in

CIVIL ENGINEERING

By

Mohamed Aly Ahmed Fergala

Assistant Lecturer in Public Works Section
Civil Engineering Department
Faculty of Engineering
Ain Shams University

This dissertation for the Ph.D. degree had been approved by :-

Prof. Dr. Ibrahim Helal El-Hatab. I. El-Hatab

Professor of Sanitary Eng., Faculty of Eng., Cairo University.

Prof. Dr. Hamdi Ibrahim Ali. Hamdy I. Ali

Professor of Sanitary Eng., Faculty of Eng., Ain Shams University.

Prof. Dr. Medhat Mohamed Saleh. M. A Saleh

Professor of Sanitary Eng., Faculty of Eng., Al-Azhar University.

Dr. ir. Sameh Sayed. Sameh

Head Department Wat. Pol. Cont., Van Hall Institute, The Netherlands.

1995

ACKNOWLEDGEMENT

The candidate is very grateful for helps and encouragement provided by :-

Professors who supervised the dissertation, viz. :

Prof. Dr. H.I. Ali

Dr. Ir. S.K.I. Sayed

Persons who cooperated for the completion of the dissertation, viz. :

L. Groendijk

A.H.W.P. Leber

G.J.P. Truyen

R. de Witt

F. Wichers

Institutions in which the dissertation was carried out, viz. :

Van Hall Institute, Holland

Laboratory of Sanitary Eng., Faculty of Eng., Egypt

M.A.A. Fergala

1995

ABSTRACT

This dissertation investigates and evaluates the Anaerobic Treatment of Domestic Sewage (Low-Strength Complex Wastewater) using the UASB Process and the factors affecting the treatment performance. The experimental results indicated that the most effective way to apply the anaerobic concept for sewage treatment is the use of Two Flocculent Sludge UASB Reactors operated alternatively (HRT ≥ 6 hrs, VLR ≤ 5 kgCOD/m^3/day, Feed Period ≤ 7 days). However, the post-treatment step is still essential to meet the stringent effluent standards. The results showed that the use of an Aerobic Activated Sludge Process (HRT ≅ 4 hrs), followed by a Packaged-Bed Denitrifying Reactor (HRT ≅ 3 hrs), are very effective as post-treatment steps, particularly for the complete removal of Nitrogen.

Stater
Appro
Ackno
Abstr
Summ
List o
List o

CHAPT
INTRO
-1 Th
-2 Th
1-2
1-2
1-2
1-2
-3 Th
Sev
1-3
1-3
-4 Sys
Sev
-5 Sco

HAPTE
ATERI
-1 The
-2 Mat
2-2-
2-2-
2-2-
2-2-
2-4-
2-2-

SUMMARY

The main target of the prevailing study is the assessment of the Anaerobic Treatment of Complex Wastewaters which contribute 40-60% of slowly-biodegradable suspended solids on COD-basis. The study was focussed on Domestic Sewage (Low-Strength Complex Wastewater) because this waste is by far the largest in volume particularly in developing countries which behave high increasing rates of population.

The treatment process was evaluated using both types of anaerobic sludge (Flocculent & Granular) under the Upflow Anaerobic Sludge Blanket (UASB) process concept at moderate temperature (18-20°C).

The experimental results showed that the most suitable approach to apply an effective treatment using the UASB process is to employ Two Flocculent Sludge Reactors operated alternatively (HRT ≥ 6 hrs, VLR ≤ 5 kgCOD/m^3/day, Feed Period ≤ 7 days) to attain good sludge stabilization extend (70% at 20°C). The maximum removal rate that can be obtained in this case is 50-55% on COD-bais and 70-75% on BOD-basis. Moreover a high content of Ammonia-Nitrogen is contained in the produced effluent. Hence, a post-treatment setp is always essential to dispose such effluent into water recipients or to reuse it in agricultural or industrial purposes satisfactorily.

The conducted further experimental research indicated that the use of an Aerobic Activated Sludge Process is very effective to be applied as a post-treatmentt step, particularly in removing the Ammonia-Nitrogen within HRT of 4 hrs only in the aeration tank (Nitrification).

The investigations conducted to assess the feasibility of the Attached-Growth (Immobilized) Systems for the complete removal of Nitrogen (Nitrification & Denitrification) indicated that the Nitrifying Packed-Bed Reactor is still in need of great modifications especially with respect to the aeration process. On the other hand, the Denitrifying Packed-Bed Reactor exploited a high treating response for the completion of the nitrogeneous compounds (Nitrates) within HRT ≤ 3.0 hrs.

CONTENTS *(cont'd)*

	Page
2-2-7 The Raw Domestic Sewage.	49
2-3 Methods.	52
2-3-1 The Methanogenic Acivity of Anaerobic Sludge.	52
2-3-2 Gas Measurement and Composition.	56
2-3-3 Wastewater and Sludge Analysis.	57
CHAPTER THREE :	
THE ANAEROBIC TREATABILITY AND BIODEGRADABILITY	
OF DOMESTIC SEWAGE.	60
3-1 The Set-Up of The Anaeobic Treatability Experiments with Domestic Sewage.	60
3-2 The Evaluation of Results of The Anaerobic Treatability & Biodegradability Experiments with Domestic Sewage.	65
3-2-1 The Various Fractions of COD.	66
3-2-2 The Balance of The Total COD.	66
3-2-3 The Anaerobic Treatability of Sewage.	67
3-2-4 The Methanogenic Activity of Sludge.	68
3-3 The Anaerobic Treatability & Biodegradability of Domestic Sewage in The Recirculation Batch Digester (RBD) inoculated with Flocculent Sludge.	68
3-3-1 Experiments with Flocculent Sludge at 20°C.	68
3-3-2 Experiments with Flocculent Sludge at 30°C.	73
3-3 The Anaerobic Treatability & Biodegradability of Domestic Sewage in The Recirculation Batch Digester (RBD) inoculated with Flocculent Sludge.	68
3-3-1 Experiments with Flocculent Sludge at 20°C.	68
3-3-2 Experiments with Flocculent Sludge at 30°C.	73
3-4 The Anaerobic Treatability & Biodegradability of Domestic Sewage in The Recirculation Batch Digester (RBD) inoculated with Granular Sludge.	75
3-4-1 Experiments with Granular Sludge at 20°C.	75
3-4-2 Experiments with Granular Sludge at 30°C.	79
3-5 Indetification of The Anaerobic Treatment Process of Sewage.	81

CONTENTS *(cont'd)*

Page

CHAPTER FOUR :
THE ANAEROBIC TREATMENT OF DOMESTIC SEWAGE
IN ONE-STAGE FLOCCULENT SLUDGE REACTOR *88*

4-1 The Experimental Set-Up of One-Stage Flocculent Sludge UASB Reactor System. *89*

4-2 Performance of One-Stage Flocculent Sludge UASB Reactor. *91*

4-2-1 The Composition of The Influent & Effluent Sewage. *91*

4-2-2 The Treatment Efficiency. *91*

4-2-3 The Gas Production. *95*

4-2-4 The COD-Balance and The Sludge Accumulation.

4-3 Treatability of Domestic Sewage in One-Stage Flocculent Sludge UASB Reactor. *103*

4-4 The Break-Through Phenomenon. *106*

4-4-1 The Break-Through at HRT = 8.0 hours. *107*

4-4-2 The Break-Through at HRT = 6.0 hours. *107*

4-4-3 The Break-Through at HRT = 4.0 hours. *108*

4-5 The Intermittent Operation of Flocculent Sludge UASB Reactors. *110*

CHAPTER FIVE :
THE ANAEROBIC TREATMENT OF DOMESTIC SEWAGE
IN TWO-STAGE UASB REACTOR SYSTEM. *111*

5-1 The Experimental Set-Up of The Two-Stage UASB Pilot Plant. *113*

5-2 The Start-Up of The Two-Stage UASB Pilot Plant. *116*

5-3 The Steady-State Operation of The Two-Stage UASB Pilot Plant. *117*

5-4 The Evaluation of Experimental Results of The Two-Stage UASB Reactor System. *120*

5-5 The Performance of The Two-Stage UASB Reactor System for Treatment of Raw Domestic Sewage. *122*

5-1-1 The Effluent Quality. *122*

5-5-2 The Treatment Efficiency. *127*

5-5-3 The Gas Production. *136*

5-5-4 The COD-Balance and The Sludge Production. *142*

5-5-5 The Sludge Retention and The Methanogenic Activity. *148*

CONTENTS *(cont'd)*

	Page
CHAPTER SIX :	
THE POST TREATMENT OF THE ANAEROBICALLY-	
(PRE)TREATED DOMESTIC SEWAGE.	*155*
6-1 The concept of The Post Treatment Process.	*155*
6-2 The Set-Up of The Post Treatment Step.	*157*
6-3 The Performance of The Aerobic Post Treatment Process.	*159*
6-3-1 The Course of The Effluent Quality.	*159*
6-3-2 The Nitrification Efficiency.	*163*
6-3-3 Bulking of Activated Sludge.	*168*
CHAPTER SEVEN :	
GENERAL DISCUSSION AND CONCLUSIONS.	*174*
7-1 Anaerobic Treatment of Domestic Sewage.	*174*
7-2 The Efficiency of The Gas-Solids Separator (GSS).	*175*
7-3 The Anaerobic Treatability and Biodegradability of Domestic Sewage.	*178*
7-4 The Application of The UASB Process for Treatment of Domestic Sewage.	*179*
7-5 The Aerobic Post Treatment.	*182*
7-6 The Anaerobic-Aerobic Treatment of Domestic Sewage.	*184*
REFERENCES.	*189*
SUMMARY IN ARABIC.	

List of Figures

		Page
Fig.(1-1) :	The Position of Anaerobic Treatment in an Economical and Recovey Treatment Technology.	4
Fig.(1-2) :	The General Scheme of The Main Processes during The Anaerobic Digestion of Complex Organics.	7
Fig.(1-3) :	Schematic Diagram of a Full-Scale UASB Reactor System.	17
Fig.(1-4) :	The Commen Up-Flow Systems used for Anaerobic Wastewater Treatment.	19
Fig.(1-5) :	Percentage of Methane Gas Dissolved in The Effluent as a Function of The Influent COD.	27
Fig.(1-6) :	The Gas-Solids Separators used for Up-Flow Reactors.	30
Fig.(2-1) :	The Modified GSS for Flocculent Sludge UASB Reactor.	38
Fig.(2-2) :	The Modified GSS for Granular Sludge UASB reactor.	38
Fig.(2-3) :	The Recirculation Batch Digester (RBD) Syste.	40
Fig.(2-4) :	The Continuously-Operated One-Stage Flocculent Sludge UASB Reactor.	44
Fig.(2-5) :	The Two-Stage Flocculent-Granular Sludge UASB Reactor System.	46
Fig.(2-6) :	The Completely-Mixed Aeration Process for Post Treatment of Domestic Sewage.	48
Fig.(2-7) :	The General Layout of The Source of Domestic sewage.	50
Fig.(3-1) :	The General Schematic Diagram of The Anaerobic Degradation of Various Fractions of Unacidified COD.	61
Fig.(3-2) :	The Total COD Balance of Domestic Sewage in Batch Experiments with Flocculent Sludge at 20°C.	69
Fig.(3-3) :	The Total COD Balance of Domestic Sewage in Batch Experiments with Flocculent Sludge at 30°C.	74
Fig.(3-4) :	The Total COD Balance of Domestic Sewage in Batch Experiments with Granular Sludge at 20°C.	76
Fig.(3-5) :	The Total COD Balance of Domestic Sewage in Batch Experiments with Granular Sludge at 30°C.	80
Fig.(4-1) :	The Response of One-Stage Flocculent Sludge UASB Reactor	

List of Figures *(cont'd)*

		Page
	for Sewage Treatment in terms of COD (HRT=8.0 hours).	92
Fig.(4-2) :	The Response of One-Stage Flocculent Sludge UASB Reactor for Sewage Treatment in terms of COD (HRT=6.0 hours).	93
Fig.(4-3) :	The Response of One-Stage Flocculent Sludge UASB Reactor for Sewage Treatment in terms of COD (HRT=4.0 hours).	94
Fig.(4-4) :	The Course of The COD Removal & The Gas Production of One-Stage Flocculent Sludge UASB Reactor (HRT=8.0 hours).	96
Fig.(4-5) :	The Course of The COD Removal & The Gas Production of One-Stage Flocculent Sludge UASB Reactor (HRT=6.0 hours).	97
Fig.(4-6) :	The Course of The COD Removal & The Gas Production of One-Stage Flocculent Sludge UASB Reactor (HRT=4.0 hours).	98
Fig.(4-7) :	The Progress of The COD Accumulation within One-Stage Flocculent Sludge UASB Reactor at HRT = 8.0 hours.	100
Fig.(4-8) :	The Progress of The COD Accumulation within One-Stage Flocculent Sludge UASB Reactor at HRT = 6.0 hours.	101
Fig.(4-9) :	The Progress of The COD Accumulation within One-Stage Flocculent Sludge UASB Reactor at HRT = 4.0 hours.	102
Fig.(5-1) :	The Effluent COD_{tot} of Domestic Sewage from The Two-Stage Flocculent-Granular Sludge Reactor System.	123
Fig.(5-2) :	The Effluent BOD_5 of Domestic Sewage from The Two-Stage Flocculent-Granular Sludge Reactor System.	124
Fig.(5-3) :	The Effluent TSS of Domestic Sewage from The Two-Stage Flocculent-Granular Sludge Reactor System.	125
Fig.(5-4) :	The Progress of COD Reduction in The Two-Stage UASB System over The Entire Experimental Period.	128
Fig.(5-5) :	The Efficiency of COD_{ss} in The Two-Stage Flocculent-Granular Sludge UASB System.	129
Fig.(5-6) :	The Progress of BOD_5 Reduction in The Two-Stage UASB System over The Entire Experimental Period.	133
Fig.(5-7) :	The Course of Nitrogen Removal Efficiency in The Two-Stage UASB Reactor System during Sewage Treatment.	134
Fig.(5-8) :	The Course of Phosphorus Removal Efficiency in The Two-Stage UASB Reactor System during Sewage Treatment.	135

List of Figures *(cont'd)*

		Page
Fig.(5-9) :	Progress of The COD_{rem}-Balance in The First Stage Reactors during The Entire Experimental Period.	*143*
Fig.(5-10) :	Progress of The COD_{rem}-Balance in The Second Stage Reactor during The Entire Experimental Period.	*144*
Fig.(5-11) :	The Relationship between Sludge Accumulation Factor (Y_{acc}) and Organic Loading Rate (VLR) of The First Stage.	*147*
Fig.(6-1) :	The Course of The Effluent Quality upon The Application of Aerobic Post-Treatment Step for The Anaerobically (Pre)treated Domestic Sewage in UASB Reactor.	*160*
Fig.(6-2) :	Development of Nitrogen-Kjeldahl (TKN) Reduction in Aerobic Post-Treatment Process after Anaerobic (Pre) Treatment of Sewage.	*165*
Fig.(6-3) :	The Course of Removal of Nitrogen-Ammonia ($N-NH_4$) upon The Application of Aerobic Post-Treatment Step for The Anaerobically (Pre)treated Sewage.	*166*
Fig.(6-4) :	Development of Total Phosphorus (P_{tot}) Reduction in Aerobic Post-Treatment Process after Anaerobic (Pre) treatment of Sewage.	*167*
Fig.(6-5) :	Development of Various Fractions of Total-Nitrogen of The Effluent after The Aerobic Post-Treatment Process.	*165*
Fig.(6-6) :	Development of Sludge Volume Index (SVI) of Activated Sludge of The Aerobic Post-Treatment Process.	*171*
Fig.(7-1) :	A Proposed Schematic Diagram of a Full-Scale UASB Reactor System.	*177*
Fig.(7-2) :	The Proposed Treatment System for Complete Carbon Oxidation & Nitrogen Removal of Raw Domestic Sewage.	*185*

List of Tables

		Page
Table (1-1) :	Some of Anaerobic Conversions of Organic Compounds.	8
Table (1-2) :	The Main Physiological Characteristics of The Different Bacterial Populations involved in Mesophilic Anaerobic Digestion.	11
Table (1-3) :	Types of Bacteria with respect to The Optimum Growth Temperature.	12
Table (1-4) :	The Classification of Wastewater with respect to Strength (COD mg/l) under Anaerobic Treatment Conditions.	23
Table (1-5) :	Some Results of The Anaerobic Treatment of Domestic Sewage in The UASB Reactor System.	24
Table (2-1) :	The Overall-Schedule of Experimental Work Conducted during The Prevailing Study.	37
Table (2-2) :	The Dimensions of The Batch Digester (RBD) Systems for Treatability & Biodegradability Experiments of Domestic Sewage.	42
Table (2-3) :	Dimensions of The Continuously-Operated Flocculent Sludge UASB Reactors.	43
Table (2-4) :	Dimensions of Reactors of Two-Stage Flocculent-Granular Sludge UASB reactor System.	45
Table (2-5) :	Details of The Dimensions of The Aerobic Post-Treatment System.	47
Table (2-6) :	The Pysico-Chemical Characteristics of Domestic Sewage over The Entire Experimental Period.	51
Table (2-7) :	Composition of Stock Solutions of Nutriants and Trace Elements for Anaerobic Methanogenic Activity Assays.	54
Table (2-8) :	The Procedures of Calculation of The Various Wastewater COD Fractions.	58
Table (3-1) :	The Recirculation Batch Experiments with Domestic Sewage.	62
Table (3-2) :	The Characteristics of Flocculent Sludge and Granular Sludge used in The Recirculation Batch Experiments.	63