



Cairo University

MODIFIED KINETIC-HYDRAULIC UASB REACTOR MODEL TREATING BIODEGRADABLE ORGANIC SUBSTRATES IN WASTEWATER

By

Mostafa Mohammad El-Seddik Ali Hussein

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
in
Civil Engineering-Public Works

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Under the Supervision of

Prof. Dr. Hisham S. Abdel-Halim

Dr. Ahmed G. A. Radwan

.....
Professor of Sanitary and Environmental
Engineering, Civil Engineering
Department
Faculty of Engineering, Cairo University

.....
Associate Professor
Engineering Mathematics Department,
Editor-in-Chief of AETA
Faculty of Engineering, Cairo University

Dr. Mona M. Galal El-Din

.....
Assistant Professor of Sanitary and
Environmental Engineering, Civil
Engineering Department
Faculty of Engineering, Cairo University

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Approved by the
Examining Committee

Prof. Dr. Hisham Sayed Abdel-Halim, Thesis Main Advisor

Prof. Dr. Ehab Mohammad Rashed, Internal Examiner

Prof. Dr. Mohammad Said El-Khouly, External Examiner
(*Prof. of Sanitary & Environmental Eng., Faculty of Eng., Ain Shams University*)

Assoc. Prof. Dr. Ahmed Gomaa Ahmed Radwan, Member

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2016

Engineer's Name: Mostafa Mohammad El-Seddik Ali
Date of Birth: 2/2/1985
Nationality: Egyptian
E-mail: mostafaelseddek@yahoo.com
Phone: 01097931177 – 01223623360
Address: 6 October City- 309 fifth quarter
Registration Date: 1/10/2011
Awarding Date:/....../2016
Degree: Doctor of Philosophy
Department: Civil Engineering-Public Works



Supervisors:

Prof. Hisham Sayed Abdel-Halim
Dr. Ahmed Gomaa Ahmed Radwan
Dr. Mona Mohammad Galal El-Din

Examiners:

Prof. Hisham Sayed Abdel-Halim (Thesis main advisor)
Prof. Ehab Mohammad Rashed (Internal examiner)
Prof. Mohammad Said El-Khouly (External examiner)
(*Prof. of Sanitary & Environ. Eng., Faculty of Eng., Ain Shams University*)
Assoc. Prof. Ahmed Gomaa Ahmed Radwan (Member)

Title of Thesis:

Modified Kinetic-Hydraulic UASB Reactor Model Treating Biodegradable Organic Substrates in Wastewater

Key Words:

acetic acid degradation; fractional order; modified model; UASB reactor

Summary:

Mathematical modeling of Up-flow Anaerobic Sludge Blanket (UASB) reactor plays a crucial role in biological wastewater treatment. Some available models of a UASB reactor are discussed in order to modify their drawbacks and propose a new improved model with less complexity and more reliability. This thesis presents a modified kinetic-hydraulic model for UASB reactor treating wastewater involved by biodegradable organic substrates based on Van der Meer model incorporated with biological granules. This model illustrates the biogas production rate as well as biomass concentration in bed and blanket zones during acetic acid biodegradation in reactor. The model is also used to determine the suitable pH value for substrate degradation by microorganisms. Moreover, a fractional order model is presented for UASB reactor aimed for better interpretation of low-strength substrate biodegradation in wastewater treatment. Numerical technique is applied to obtain the influence of fractional order derivatives on both modified UASB reactor and conventional models utilizing low/high-strength substrates. Furthermore, the results of the modified model can be adapted using extra degree of freedom to match the measured results of Sanhour wastewater treatment plant in Fayoum, Egypt.

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Dedication

This thesis shall be dedicated to my family for their support and help to me in all times with patience, love and hope. I thank Allah for guide and blessings that ever enhances this work.

Table of Contents

ACKNOWLEDGMENTS.....	V
DEDICATION	VI
TABLE OF CONTENTS	VII
LIST OF TABLES	IX
LIST OF FIGURES	X
NOMENCLATURE.....	XIV
ABSTRACT	XV
CHAPTER 1 : INTRODUCTION.....	1
1.1.MOTIVATION OF RESEARCH.....	1
1.2.THE SCOPE OF THESIS	2
1.3.ORGANIZATION OF THESIS.....	3
CHAPTER 2 : ANAEROBIC WASTEWATER TREATMENT	4
2.1. ANAEROBIC DIGESTION	4
2.2. ANAEROBIC REACTORS.....	6
2.2.1. Conventional anaerobic systems	6
2.2.1.1. Anaerobic digesters.....	6
2.2.1.1.1. Low-rate anaerobic sludge digester.....	6
2.2.1.1.2. High-rate anaerobic sludge digester.....	6
2.2.1.2. Septic tanks.....	6
2.2.1.3. Anaerobic ponds.....	7
2.2.2. Advanced anaerobic systems	7
2.2.2.1. Suspended growth bacteria process.....	7
2.2.2.1.1. Complete-mix digester	7
2.2.2.1.2. Anaerobic sequencing batch reactor.....	7
2.2.2.1.3. Up-flow anaerobic blanket reactor.....	8
2.2.2.1.4. Expanded granular sludge bed reactor.....	8
2.2.2.2. Attached growth bacteria process.....	9
2.3. UP-FLOW ANAEROBIC SLUDGE BLANKET (UASB) REACTOR.....	9
2.3.1. Factors affecting UASB reactor.....	10
2.3.2. Granule development.....	12
2.3.2.1. Physical phenomena.....	12
2.3.2.2. Microbial phenomena.....	13
2.3.2.3. Thermodynamic phenomena.....	13
2.4. EXAMPLES OF THE UASB REACTORS.....	14
2.5. RECENT UASB MODELS.....	16
2.5.1. Model I proposed by Wu and Hickey (1997).....	16
2.5.2. Model II proposed by Pontes and Pinto (2006).....	18
2.5.3. Model III proposed by Larisa Korsak, USA (2008).....	19
2.5.4. Model IV proposed by Olafadehan, Nigeria (2009).....	23
2.5.5. Model V proposed by Parsamehr, Sweden (2012).....	27
2.6. HISTORY OF FRACTIONAL CALCULUS.....	37

2.6.1. Fractional integral and derivative.....	39
2.6.1.1. Euler's Gamma Function.....	40
2.6.1.2. Beta Function.....	40
2.6.1.3. Laplace Transform.....	41
2.6.1.4. Mittag-Leffler Function.....	41
2.6.2. Definitions and notations.....	41
2.6.2.1. Fraction integral equations.....	42
2.6.2.2. Fractional differential equations.....	43
2.6.3. Applications of fractional order systems.....	45
2.6.3.1. Control systems.....	45
2.6.3.2. Biochemical systems.....	46
2.6.3.3. Biological systems.....	46
2.6.3.4. Mechanical systems.....	46
2.6.3.5. Physical systems.....	46
2.6.3.5.1. Circuits with fractional order oscillators.....	47
CHAPTER 3 : MODIFIED KINETIC-HYDRAULIC MODEL	48
3.1. MODIFIED KINETIC MODEL DESCRIPTION.....	48
3.2. MODIFIED HYDRAULIC MODEL DESCRIPTION.....	49
3.3. KINETIC PARAMETERS IN UASB REACTOR.....	51
3.4. COD AND BIOGAS SIMULATIONS IN MODIFIED KINETIC MODEL.....	53
3.5. INFLUENCE OF FLOW DISPERSION AND PH VALUE ON UASB PERFORMANCE.....	55
3.6. STEADY STATE RESPONSE OF REACTOR.....	56
3.7. SENSITIVITY ANALYSIS OF MODIFIED MODEL.....	58
3.8. EXPERIMENTAL RESULTS.....	62
3.8.1. Analytical results for pilot UASB in Zenien WWTP, Egypt.....	63
3.8.2. Description of Sanhour plant in Egypt.....	64
3.8.3. Performance of UASB reactor in Sanhour plant.....	65
3.8.4. Verification of the modified model of reactor.....	66
CHAPTER 4 : FRACTIONAL ORDER DYNAMIC MODELS	68
4.1. WASTEWATER TREATMENT USING FRACTIONAL MODELING.....	68
4.2. FRACTIONAL ORDER MODEL DESCRIPTION.....	69
4.3. UASB SIMULATIONS USING FRACTIONAL ORDER MODEL A.....	71
4.3.1. Fractional Order Model (FOM) using constant order.....	73
4.3.2. Fractional Order Model (FOM) using different orders.....	77
4.4. UASB SIMULATIONS USING FRACTIONAL ORDER MODEL B.....	80
4.4.1. Steady state response of UASB reactor.....	80
4.5. CASE STUDY FOR THE UASB REACTOR.....	82
4.5.1. UASB reactor performance in Zenien pilot plant.....	82
4.5.2. Validation of fractional order model of UASB reactor.....	84
CONCLUSIONS	86
REFERENCES.....	88
APPENDIX A: LABORATORY TESTS IN ZENIEN PLANT	92

List of Tables

Table 2.1 - Flow parameters for Larisa Korsak model	20
Table 2.2 - Kinetic parameters for Larisa Korsak model.....	21
Table 2.3 - Flow parameters for Olafadehan model	25
Table 2.4 - Kinetic parameters for Olafadehan model.....	25
Table 2.5 - Kinetic equations found in literature for anaerobic digestion of organic substrates in UASB reactors.....	29
Table 2.6 - Flow parameters for Parsamehr model.....	30
Table 2.7 - Kinetic parameters for Parsamehr model	30
Table 3.1 - Measured laboratory results for UASB Sanhour WWTP, Fayoum Egypt.....	66
Table 3.2 - Values of kinetic parameters assessed for acetic acid substrate in the UASB reactor model.....	67
Table 3.3 - Characteristics of domestic wastewater in UASB reactors at Sanhour plant in Fayoum, Egypt	67
Table 4.1 - Characteristics of wastewater and sludge in Zenien and El-Gabal El-Asfer WWTPs	85
Table 4.2 - Measured laboratory results for pilot UASB reactor in Zenien WWTP, Egypt.....	85

List of Figures

Fig.2.1: Degradation of substrate into less complex organic matter	5
Fig.2.2: A block diagram for substrate degradation in UASB reactor [49]	5
Fig.2.3: Flow chart of the processes occurred during anaerobic digestion of organic matter in UASB reactor.....	5
Fig.2.4: Anaerobic digestion in the Northwest (Source: Dan Sallivan, BioCycle March 2012, Vol. 53, No.3, pp.33).....	8
Fig.2.5: Anaerobic batch reactors-CA-SCS-Engineers (Published on October 8, 2015) 8	
Fig.2.6: General view of the UASB reactor (Source: http://www.eurotecwtt.it)	10
Fig.2.7: Description of wastewater treatment in UASB and EGSB reactors	11
Fig.2.8: Bacterial cell structure of UASB granule.....	12
Fig.2.9: Biological granules in UASB reactors (Source: Lettinga Associates Foundation, 2010).....	13
Fig.2.10: Initial morphology of seeded UASB granules	14
Fig.2.12: Industrial WWTP, India	14
Fig.2.11: Biogas Plant in the UK.....	14
Fig.2.13: Sewage wastewater treatment plant in (a) India, and (b) Colombia	15
Fig.2.14: (a) UASB reactors, and (b) Trickling filters in Sanhour UASB wastewater treatment plant, Fayoum, Egypt.....	15
Fig.2.15: Schematic block diagram for UASB reactor of one zone for bed and blanket layers based on Wu and Hickey model	17
Fig.2.16: Schematic block diagram for UASB reactor comprised of two zones for bed and blanket layers based on Pontes and Pinto model.....	18
Fig.2.17: Schematic block diagram for UASB reactor of a CSTR and dispersed PFR zones based on Korsak model	19
Fig.2.18: A representation of particle granules in the UASB reactor	20
Fig.2.19: Substrate concentration versus time in the UASB reactor for Korsak model	22
Fig.2.20: Effect of variation of dispersion coefficient on the reactor performance for Korsak model.....	22
Fig.2.21: Effect of variation of diameter of granules on UASB reactor performance for Korsak model.....	22
Fig.2.22: Substrate degradation at different fractions of reactor volume occupied by granules for Korsak model	23
Fig.2.23: Schematic block diagram for reactor based on Olafadehan model.....	23
Fig.2.24: Specific growth rate of bacteria versus pH values for various substrate concentrations	26
Fig.2.25: Specific growth rate of bacteria versus substrate concentration for various pH values.....	26
Fig.2.26: Effective biomass concentration in reactor versus time for Olafadehan model	27
Fig.2.27: Substrate concentration in reactor versus time for Olafadehan model	27
Fig.2.28: Schematic block diagram for hydraulic model of the UASB reactor based on Van der Meer model	28
Fig.2.29: Substrate concentration as COD in reactor bed zone versus time for Parsamehr model.....	31
Fig.2.30: Substrate concentration as COD in reactor blanket zone versus time for Parsamehr model.....	32

Fig.2.31: Concentration of gases produced in UASB reactor bed zone versus time	32
Fig.2.32: Concentration of gases produced in UASB reactor blanket zone versus time	32
Fig.2.33: Volatile fatty acids concentration produced in UASB reactor bed zone versus time.....	33
Fig.2.34: Volatile fatty acids concentration produced in UASB reactor blanket zone versus time.....	33
Fig.2.35: Amount of methane gas produced in UASB reactor bed zone versus time ...	33
Fig.2.36: Amount of methane gas produced in UASB reactor blanket zone versus time	34
Fig.2.37: Specific growth rate of bacteria in UASB reactor bed zone versus time	34
Fig.2.38: Specific growth rate of bacteria in UASB reactor blanket zone versus time .	34
Fig.2.39: Granule particles retention time in UASB reactor bed zone versus time.....	35
Fig.2.40: Granule particles retention time in UASB reactor blanket zone versus time .	35
Fig.2.41: Biomass concentration in the reactor bed zone versus time for different yield values.....	35
Fig.2.42: Biomass concentration in the reactor blanket zone versus time for different yield values.....	36
Fig.2.43: Substrate concentration as VSS in the reactor clarifier zone versus time	36
Fig.2.44: Substrate concentration in the reactor bed zone versus time for different values of maximum specific growth rate of bacteria.....	36
Fig.2.45: Substrate concentration in the reactor blanket zone versus time for different values of maximum specific growth rate of bacteria	37
Fig.2.46: Substrate concentration in the reactor blanket zone versus time for different values of wastewater up-flow velocity and bypass flow fraction.....	37
Fig.2.47: The first simple fractional oscillator response [38, 39].....	47
Fig.3.1: (a) Flow chart of the combined kinetic model in UASB reactor, (b) schematic block diagram of the modified kinetic model of UASB reactor, and (c) schematic block diagram of the modified hydraulic model of reactor bed zone	49
Fig.3.2: Substrate degradation for modified models in reactor (a) bed and (b) blanket zones, biogas production rate versus time using different modified models in UASB reactor (c) bed and (d) blanket zones, and methane gas concentration versus time for various modified models in reactor (e) bed and (f) blanket zones.....	54
Fig.3.3: Substrate degradation (a) in reactor bed zone versus time, and (b) in reactor blanket zone versus time for Parsamehr model and developed model of $\alpha = 0.5$	55
Fig.3.4: (a) Substrate concentration in reactor bed zone versus time using flow dispersion in the modified model, ratio of specific growth rate of bacteria to maximum specific growth rate of bacteria versus unionized substrate concentration (b) at various <i>pH</i> values and (c) for kinetic parameters determination of total acetic acid concentration of 3 kg/m^3 , and (d) specific growth rate of bacteria versus <i>pH</i> regarding different temperatures for acetic acid degradation.....	56
Fig.3.5: (a) Biomass concentration in reactor bed zone for various modified models and granules amounts, fraction of volume of reactor occupied by granules versus (b) biomass concentration in reactor and (c) biomass density in reactor for the steady state condition, and (d) biomass concentration in reactor bed zone versus time during reactor start-up for various initial biomass concentrations at average kinetic model	57

Fig.3.6: Sensitivity analysis of UASB reactor modified model of $\alpha = 0.5$ at dynamic state condition.....	61
Fig.3.7: Substrate concentration in the UASB reactor (a) bed zone versus time, and (b) blanket zone versus time for variation of specific growth rate of bacteria at dynamic state of reactor modified model of $\alpha = 0.5$	61
Fig.3.8: Substrate concentration in the UASB reactor (a) bed zone versus time, and (b) blanket zone versus time for variation of wastewater up-flow velocity at dynamic state of reactor modified model of $\alpha = 0.5$	62
Fig.3.9: (a) Granule settling velocity versus particle diameter using various sludge densities and (b) chemical reaction rate versus particle diameter using various sludge thicknesses	62
Fig.3.10: Simulations of UASB reactor modified models for variation of different parameters at the steady state condition	63
Fig.3.11: UASB Sanhour WWTP in Fayoum governorate, Egypt	65
Fig.3.12: Model simulations of the UASB Sanhour wastewater treatment plant results for different models in reactor (a) bed and (b) blanket zone	67
Fig.4.1: Schematic block diagram of the fractional order model for microorganisms during substrate degradation in UASB reactor (a) Model A and (b) Model B	70
Fig.4.2: (a) biomass concentration, and (b) substrate concentration in UASB reactor at steady state using Model A for different temperatures and pH values.....	72
Fig.4.3: (a) biomass concentration, (b) substrate concentration, (c) specific growth rate of bacteria, and (d) biogas production rate in UASB reactor using various fractional order models at the dynamic state of UASB reactor Model A	72
Fig.4.4: reactor performance using integer order model at various HRT	73
Fig.4.5: UASB reactor performance using FOM of constant order ($\beta = 0.9$) at various HRT	74
Fig.4.6: UASB reactor performance using FOM of constant order ($\beta = 0.8$) at various HRT	75
Fig.4.7: UASB reactor performance using FOM of constant order ($\beta = 0.7$) at various HRT	75
Fig.4.8: sensitivity analysis of reactor to FOM of constant order at HRT= 6 hr	76
Fig.4.9: sensitivity analysis of reactor to FOM of different order at HRT= 6 hr	76
Fig.4.10: UASB reactor performance using FOM of different order ($\beta_1 = 0.9, \beta_2 = 1.0$) at various HRT	77
Fig.4.11: UASB reactor performance using FOM of different order ($\beta_1 = 0.7, \beta_2 = 0.9$) at various HRT	78
Fig.4.12: UASB reactor performance using FOM ($\beta_1 = 0.7 - 0.9, \beta_2 = 0.7$) at HRT= 6 hr	78
Fig.4.13: UASB reactor performance using FOM ($\beta_1 = 0.7 - 0.9, \beta_2 = 0.8$) at HRT= 6 hr	79
Fig.4.14: UASB reactor performance using FOM ($\beta_1 = 0.7 - 0.9, \beta_2 = 0.9$) at HRT= 6 hr	79
Fig.4.15: FOM simulations of the UASB Sanhour WWTP results regarding (a) substrate degradation, and (b) biogas production rate in reactor.....	80
Fig.4.16: (a) Biomass concentration in reactor bed zone for various modified models using different fractional orders at the steady state of reactor, (b) specific growth rate of bacteria, (c) substrate concentration, and (d) biogas production rate in reactor bed zone using various fractional models during the dynamic state of reactor Model B	81

Fig.4.17: Simulations of the UASB reactor modified models for variation of different amount of granules at the steady state condition of Model B	82
Fig.4.18: A diagram for the pilot UASB reactor at Zenien WWTP in Giza governorate, Egypt	83
Fig.4.19: Model simulations of the pilot UASB Zenien WWTP results for fractional order modified model regarding (a) substrate degradation and (b) biogas production rate in reactor	84

Nomenclature

AEBR Anaerobic Expanded Bed Reactor

BOD Biochemical Oxygen Demand

COD Chemical Oxygen Demand

CSTR Continuous Stirred Tank Reactor

EGSB Expanded Granular Sludge Bed

FBR Fluidized Bed Reactor

FOM Fractional Order Model

HRT Hydraulic Retention Time

OLR Organic Loading Rate

PFR Plug Flow Reactor

SRT Solids Retention Time

TSS Total Suspended Solids

UASB Up-flow Anaerobic Sludge Blanket

VSS Volatile Suspended Solids

WWTP Wastewater Treatment Plant

Abstract

This thesis addresses a modified kinetic-hydraulic model for Up-flow Anaerobic Sludge Blanket (UASB) reactor aimed to treat wastewater of biodegradable organic substrates as acetic acid based on Van der Meer model incorporated with biological granules inclusion. This dynamic model illustrates the biomass kinetic reaction rate for both direct and indirect growth of microorganisms coupled with the amount of biogas produced by methanogenic bacteria in bed and blanket zones of reactor. Moreover, the pH value required for substrate degradation at the peak specific growth rate of bacteria is discussed for Andrews' kinetics. The sensitivity analyses of biomass concentration with respect to fraction of volume of reactor occupied by granules and up-flow velocity are also demonstrated. In addition, the modified mass balance equations of reactor are applied during steady state using Newton Raphson technique to obtain a suitable degree of freedom for the modified model matching with the measured results of UASB Sanhour Wastewater Treatment Plant (WWTP) in Fayoum, Egypt. In a continuous elaboration, this thesis also presents a fractional order model for UASB reactor aimed for better interpretation of low-strength substrate biodegradation in wastewater treatment. An exploration of biogas production rate can be stimulated using the extra degrees of freedom of this dynamic model. Moreover, long range interactions of biomass behavior are provided for long term prediction of substrate concentration in reactor. A numerical method is applied to obtain the influence of fractional order derivatives on both modified UASB reactor and conventional models utilizing low/high-strength substrates. Thus, the modified mass balance equations are investigated during the steady state of reactor treating low-strength wastewater using Newton Raphson technique. Furthermore, the fractional order model can accordingly be enhanced with the assessed values of biomass concentrations in reactor bed and blanket zones in order to comply with the measured results of pilot UASB reactor at Zenien WWTP in Giza, Egypt.

Keywords: acetic acid degradation; fractional order; modified model; UASB reactor