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
GIZA, EGYPT
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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.

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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