

## ASPECTS ON METHANOGENIC BIOFILM REACTOR MODELING

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**Abstract**— A previously developed deterministic steady state module for modeling methanogenic biofilm reactors has been revised to enlarge the model application range and to deal with system dynamics. Two models for the hydrolysis of non-active biomass representing extreme alternatives: without biomass hydrolysis (model A) and with complete and instantaneous hydrolysis of non-active suspended and attached biomass (model B) were investigated. Both models resulted to be suitable for simulating highly anaerobic loaded systems. However, only model B showed good agreement between experimental and calculated values at low organic loading rates. The values of the specific biofilm detachment rate and the specific microbial death rate of the original model were re-estimated for model B based on a set of step-type disturbances on the organic loading rates. At loading rates ranging between 2 to 4 g COD per day per liter of expanded bed applied to a lab-scale fluidized bed reactor, the parameter estimates were  $0.0269 \text{ Lg}^{-1}\text{d}^{-1}$  and  $0.061 \text{ d}^{-1}$  for the specific biofilm detachment rate and the specific death rate, respectively, with a 95% chi-square confidence level.

**Keywords**— Anaerobic digestion, biofilm reactor, process dynamics, biomass hydrolysis.

### I. INTRODUCTION

A deterministic dynamic model can be used for different purposes. Through numerical simulation, the dynamical behavior of processes can be predicted, empirical model parameters can be determined, experimental campaigns for discriminating the main mechanisms governing the process dynamics can be defined, and full-scale industrial processes can be optimally designed. Large changes in the environmental conditions experienced under transient behavior such as system start up or operation modes provoked by changes on the influent flow rate, chemical oxygen demand (COD) and composition, pH and concentration of inhibitory species, may deteriorate the system efficiency and, even worse, cause the process failure. Thus, the development of a dynamic bioreactor model becomes evident to address these needs. Within this context, a mathematical model for the dynamic simulation of anaerobic bioreactors containing biofilm and degrading complex substrates was presented in Mussati *et al.* (1998). The model allowed simulating different reactor configurations such as single continuous stirred tank reactor (CSTR) and in-series CSTRs to model non-ideal flow pattern. Afterwards, the model was used to investigate the most common loading strategies used for starting up anaerobic wastewater treatment systems (Mussati *et al.*, 2003). Recently, a more rigorous and refined steady state model of an anaerobic methanogenic biofilm reactor-module that accounts for the biological interactions of four microbial

groups, ionic equilibrium in solution, gas-liquid transfer phenomena and biofilm processes was presented by Mussati *et al.* (2005). The model consists of a CSTR type that allocates an inert support material, whose specific surface is taken into account. The biofilm model assumes a homogeneous biofilm of uniform thickness and constant density with no mass transfer resistance. The biofilm detachment process rate is modeled as a second-order function on the biofilm thickness and a first-order function on the mass fraction of the fixed biomass concentration of each microbial group. The balance equations for non-active biomass in liquid and biofilm are included. The model predictions have been satisfactorily compared with steady state experimental data reported in literature from a one-phase methanogenic biofilm system treating an acetic acid-based synthetic effluent and from a two-phase system with combined suspended (acidogenic) and attached (methanogenic) microbial growth treating a food industry wastewater composed by two residual process streams. These satisfactory results were obtained dealing mainly with highly loaded systems.

However, at low COD loading rates the *dynamic* biofilm reactor model derived from the steady state reactor module failed in predicting the effluent (transient) biomass concentration and total COD for treating a liquid stream composed mostly by acetic acid in an anaerobic fluidized bed reactor. Nevertheless, a good agreement between experimental and predicted values was observed for critical process variables influencing the system performance, such as pH, VFA and biogas production rate. Thus, the focus was on the model of the biological processes where biomass is directly involved; more specifically on the kinetic model and parameter values for the acetoclastic methanogenic step. Sensitivity studies have shown that changes on the model parameter values provide no better predictions of the suspended biomass concentration and total COD at low loading rates. As conclusion, a refinement of the original steady state module model is required to capture more accurately the process dynamics when simulating low loaded anaerobic biofilm reactors.

This paper is then intended to present an alternative to the previously developed deterministic model by improving the modeling of the biological stages and their associated process rates to enlarge the model application range when dealing with system dynamics. The focus is mainly on revising the biofilm system model (more specifically the detachment rate coefficient) and the specific death rate of microorganisms, and considering a