Mathematical Modelling of Uasb Reactor for Dairy Wastewater Treatment

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ABSTRACT   *A mathematical model was conducted to describing the main microbial processes, occurring in the UASB reactor leading to the production of biogas from dairy waste water. In the model, the UASB reactor is divided in four well-stirred reactors coupled in series and it comprises substrate degradation, biomass growth and death with time and the washout of microorganisms, the reactions that take place within the granules. The important outline of the paper is the development of a UASB reactor model taking into account the mass balances for substrate degradation and microorganisms growth. The simulated results of UASB reactor treating dairy wastewater were found to be in good agreement with the experimental results. This model is a useful tool in the optimization and development of UASB reactors.*

1. INTRODUCTION

Discharges of inadequately or untreated wastewater may have a great impact on natural water sources. The treatment of wastewater has been an issue of high priority in most industrial countries and they have therefore reached a very satisfactory quality of their wastewater discharges. However, due to economic factors, attitudes and education, the developing countries have problems in the treatment of residual water. In some cases, industrial wastewaters are discharged directly into public collection systems, and this affects the performance of the treatment plants. In many countries, wastewater is discharged directly into rivers or lagoons with damage to the aquatic life and to the quality of the water sources. Wastewater with high amounts of nutrients and organic material may cause eutrophication. This problem could be solved by improving the wastewater-treatment system. There are two main types of biological processes for the treatment of dairy wastewaters with a high content of organic material: aerobic processes and anaerobic processes. (Tchobanoglous et al. 2003).

Aerobic biological treatment involves microbial degradation and oxidation of waste in the presence of oxygen. Conventional treatment of dairy wastewater by aerobic processes includes processes such as activated sludge, trickling filters, aerated lagoons, or a combination of these (Carta-Escobar et al.,2004). All compounds of dairy wastewater are biodegradable except protein and fats which are not easily degrades (Omil et al.,2003).

Aerobic Mechanism:
Organic matter + microorganisms + O_2 5CO_2 + $_2H_2O$ + NH_3 + energy
Anaerobic microorganisms are those that do not have oxygen as a terminal electron acceptor. The oxidation of organic matter in anaerobic respiration is coupled with the reduction of other electron acceptors such as sulphate (sulphate reduction), ferric iron (iron reduction), nitrate (denitrification), CO2 (methanogenesis) or some organic compounds. An anaerobic process involves the degradation of complex high-molecular-weight organic compounds to mainly methane (CH4) and carbon dioxide (CO2) (Bitton, 2005).

Anaerobic Mechanism:
Organic matter + nutrients   Bacteria   new cells + CH_4 + CO_2

Then, methanogenic bacteria utilize these products to form the end product of anaerobic digestion- methane, carbon dioxide, new microorganisms and energy.

The aim of this paper is to develop a model that properly predicts the degradation of the substrate (S) in the UASB reactor and the model is transient; therefore it can handle the growth of biomass (X) with time, the variable substrate concentration at the feed, and the variable flow rate through the reactor. An important contribution of this paper is the development of an analytical expression for describing the main microbial processes, occurring in the UASB reactor leading to the production of biogas (CH4) from dairy waste water.

2. MODEL DEVELOPMENT
2.1 Assumptions:
1. The substrate is a single biodegradable substance.
2. The processes depend only on the height (H) in the reactor (one dimensional model).
3. No transition zone, is considered in the sludge distribution, The processes in any given

Cross - section of the reactor are considered to be uniform.

4. The temperature (T) is constant.
5. The kinetics follows the Monod model. It is assumed that the degradation within the granule is controlled by a single process; for example, the hydrolysis of the organic material. Acetate and methane production are considered to be rapid. (Dewil *et al., 2*008).

2.2 UASB REACTOR MODELING:
In this model, the reactor was divided into four small reactors with the same volume. The model takes into account the decay of microorganisms, the fraction of microorganisms carried out by the effluent, and the convective and reaction terms. The dispersion is accounted for in the number of small reactors. The UASB reactor divided into several small reactors (e.g. four small reactors). The kinetics follows the Monod

equation with regard to both substrate degradation and microorganism growth. The model is able to predict the behaviour of a UASB reactor that work as a CSTR reactor as shown in fig.(1). (Rodriguez and Moreno et al., 2009).
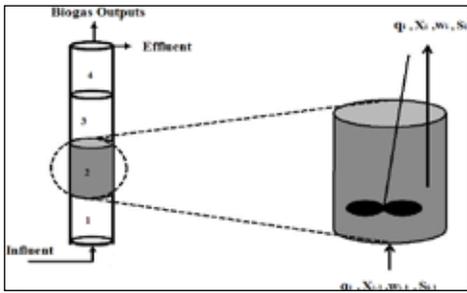

Fig.(1) UASB reactor divided into four small reactors.

To describe the UASB performance, the UASB reactor is represented as four small well-stirred reactors in series as shown in fig(1) Figure(1).

1) Mass Balance for substrate degradation –
(Rate of accumulation of substrate within the reactor) = (Rate of flow of substrate into the reactor) – (Rate of flow of substrate from the reactor) + (Rate of utilization of substrate within the reactor)

$$\frac{dS_i}{dt} = \frac{q}{V_i}(S_{i-1} - S_i) - R_s \quad (1)$$

2) Mass Balance for microorganisms growth –
(Rate of accumulation of microorganism within the reactor) = (Rate of flow of microorganism into the reactor) – (Rate of flow of microorganism from the reactor) + (Rate of growth of microorganism within the reactor).

$$\frac{dx_i}{dt} = \frac{q}{V_i}(X_{i-1} - X_i) + R_s \quad (2)$$

Assuming that the kinetics follows the Monod model, the mass balance eq. (1),(2) may be written as:

$$\frac{dS_i}{dt} = \frac{q}{V_i}(S_{i-1} - S_i) - \left(\frac{\mu_{max}}{Y_i} \cdot \frac{S_i}{K_s + S_i}\right)X_i \quad (3)$$

$$\frac{dx_i}{dt} = \frac{q}{V_i}(X_{i-1} W_{i-1} - X_i W_i) + \left(\mu_{max} \cdot \frac{S_i}{K_s + S_i} - K_d\right)X_i \quad (4)$$

Where,

Y = Yield coefficient, (the mass of biomass produced per mass of substrate degraded).

K_d = Decay constant (the rate at which the microorganisms disappear (d⁻¹)).

i = 0,1,2,3

In Equation(3), the term on the left-hand side is the accumulation term, the first term on the right-hand side is the advective term and the second is the reaction term. In Equation (4), the first term on the right-hand side is the amount of microorganisms that are washes out from the small reactors. The second term describes the growth and death of microorganisms. The dispersion in the UASB reactor is accounted for by the number of small reactors used in the system. A small number of reactors indicate a large dispersion. To solve the governing equations of the model, the MATLAB(ODE113) program was used. Experimental data was taken from the literature of previous scholars to test the model.

Table (1). Kinetics parameters (Laxmi Kant Pandey et.al.,2013)

Parameters	Symbol	Units	Values
Reactor volume	V	(L)	22.25
Inlet substrate concentration	S_o	(mg L⁻¹)	2400
Yield coefficient	Y	(mg VSS [mg COD]⁻¹)	0.000780
Decay rate	K_d	(d⁻¹)	0.093
Max. Specific growth rate	m_{max}	(d⁻¹)	0.21
Monod constant	K_s	(mg L⁻¹)	561
Initial biomass concentration	$X_{initial}$	(mg L⁻¹)	5
Initial substrate concentration	$S_{initial}$	(mg L⁻¹)	2400
washout fraction(Assume)	W	-	0.002

3. RESULTS AND DISCUSSION :
The model was run for two flow rates (3 and 9 L/day) corresponding to an HRT of 6.7(h) respectively. The washout fraction was assumed to be 0.002. Fig.3(a) and (b) shows the model response for a flow rate of 3 and 9 (L/day). These all figures shows the COD degradation in the four small reactors in the model. In reactor first at the bottom of the UASB reactor the COD concentration is reduced by 95.08%. and total removal of COD in all four reactors was 96% when the steady state was reached. Now, Laxmi Kant Pandey et. al., (2013) reported a total reduction of COD in four small reactors 90% . Due to different operation times this differences may occurs, the steady state was reached in 12 days. The microorganism behaviour is shown in Figure4(a)and(b).
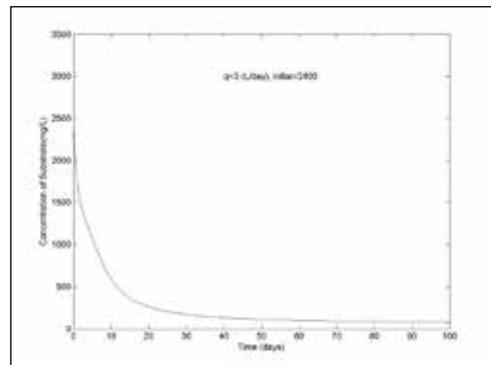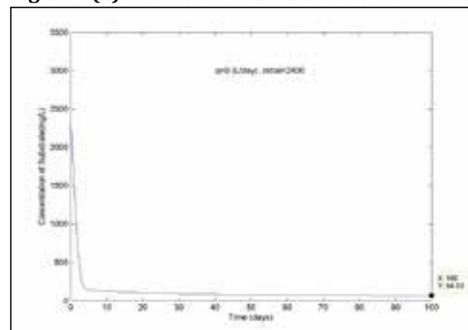

Figure 3(a). Substrate concentration versus time

Figure3(b). Substrate concentration versus time
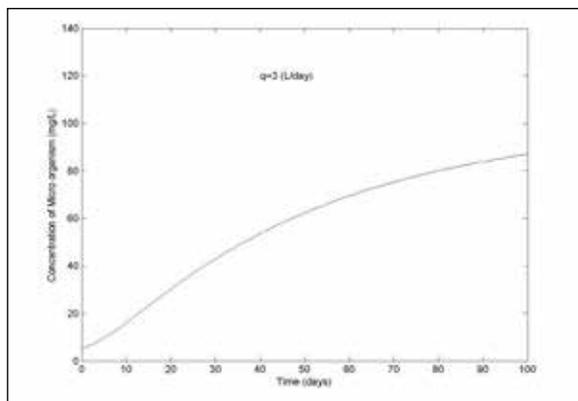
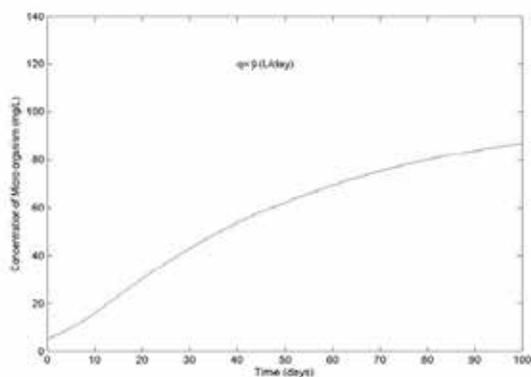**Figure4(a). Active biomass concentration versus time.**

Figure4(b). Active biomass concentration versus time.

In reactor 1, the active biomass grew at a faster rate due to the larger amount of substrate that was degraded in that reactor. The biomass growth rate was lower in the other reac-

tors because a part of the substrate had been degraded in the reactors near the inlet. The steady state was reached after 50-60 days.

4. CONCLUSIONS

A model was proposed for the Upflow Anaerobic Sludge Blanket (UASB) reactor. The proposed model describes the substrate degradation, the microorganism concentration growth and the washout of microorganisms in the reactor. This type of reactor is an attractive alternative for regions in hot climates since it works better under mesophilic conditions and it does not need any supporting structure for the development of microorganisms, which grow in the form of granules. The developed model is transient and it is based on mass balances for the substrate and microorganisms in the four reactor. The decay takes into account the microorganism dying and the fraction of biomass that may be dragged into the effluent. The microorganism development is described by a Monod type equation including the death constant (Kd). The model was solved using Matlab(ODE113) and the model was validated using results reported in the literature from experiments carried out at pilot scale. Mathematical Models like the one developed here are useful tools in the development and design of UASB reactors. It is also allows to study the consequences for the reactor performance of different types of substrate, different inlet substrate concentration, different flow rates and different kinds of biomass.

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