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Flax Retting Wastewater Part 2.Microbial Growth and Biodegradation Kinetics

Randa M. Osman*, Azza I. Hafez, Maaly A. Khedr
Chemical Engineering & Pilot Plant Department, National Research Center, Dokki, Cairo, Egypt.
*Corresponding author. E-mail: randa.osman@yahoo.com

Abstract— ***The application of kinetic models (Monod, Contois and Chen & Hashimoto) and overall microbial kinetic on the Up-flow Anaerobic Sludge Blanket Reactor (UASB) for treatment of flax retting wastewater was investigated. The system consists of a UASB reactor and six steady states were attained over a range of COD loading rates of 1.5–8.6 kg COD/m^3/d. The results of all six steady states were successfully fitted above 96% for three known kinetics. The growth yield coefficient, Y, was found to be 0.74 gVSS/gCOD while the specific microorganism decay rate was 0.20 d^{-1}. The k values were in the range of 0.3 – 0.523 gCOD/gVSS/d and μ_{max} values were between 0.259 and 0.352 d^{-1}. The COD removal efficiency was 90.5-64.5% with HRT of 72-12 hrs. The system efficiency was greatly influenced by SRT and OLRs.***

Index Terms—**Retting wastewater; anaerobic digestion; UASB; kinetic parameters.**

I. INTRODUCTION

The up flow anaerobic sludge blanket (UASB) technology is a form of anaerobic digester that is used in the treatment of low and high strength wastewater. An understanding of the process kinetics is vital in the design, development and operation of UASB reactors. Kinetics provides basis for process analysis, control and design. In addition kinetics describes the substrate utilization rates and deals with operational and environmental factors affecting these rates [1]. Bacterial growth kinetics is based on two fundamental relationships: growth rate and substrate utilization rate.

A variety of microbial growth and biodegradation kinetic models have been developed, proposed and used by many researchers as reported by [2]. Such models allow prediction of chemicals (substrates) that remain at a certain time, calculation of the time required to reduce chemicals (substrates) to certain concentration, estimation of how long it will take before certain chemical (substrate) concentration will be attained in UASB reactor and design of bioremediation schemes in situ or ex situ to remove chemical (substrate) contaminant to a designed concentration. On the other hand, it can be used to predict the amount of biomass production achievable at a given time.

Flax retting wastewater resulted from Oil and flax company in Egypt was treated an aerobically by using UASB reactor where batch and continuous treatment were investigated [3]. The aim of the present paper is to describe the performance of the UASB reactor in treating the Flax retting wastewater by three kinetic models namely Monod, Contois and Chen & Hashimoto. A comparative study by using Monod and Haldane derivatives models equations will be considered to calculate the specific growth rate of biomass in the USAB reactor.

II. DEVELOPMENT OF SOME KINETIC MODELS

Several complete structured kinetic models have been developed for the anaerobic process [4] & [5] and have been validated in practical applications [6-8]. At the cost of increasing complexity, these models are very complete and take into account a set of physico-chemical equations, incorporate gas transfer and ionic reactions and also structured biochemical equations. However, these models consider up to 26 dynamic state concentration variables per reactor vessel or element, and a deep knowledge of the system and intermediate concentrations is needed to apply these models.

Simpler models that study the variation of complex substrates using a global parameters such COD, biological oxygen demand (BOD) or volatile suspended solids (VSS) are more useful in industrial applications where usually the instruments to measure concentrations of intermediates are not available. Several authors proposed complex kinetic models to fit global parameters during anaerobic biodegradation [9-12]. However, the simplest first-order power law serial-parallel system reaction fits properly in most of the cases [13-15].

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A. Monod Model

According to literature, the UASB reactor has two distinct characteristics: the sludge bed and blanket which can be described as a combination of a completely mixed region and the flow characteristics in the setting zone which can be described as plug flow, taking account of the effect of rising gas bubbles from the sludge bed and blanket zone, the UASB reactor is assumed to be completely mixed flow.
For an UASB reactor without biomass recycle, the rate of change of biomass and substrate in the system can be expressed respectively as Eqs. (1) and (2)

$$\frac{dx}{dt} = \frac{Q}{Vb} X_o - \frac{Q}{Vb} X_e + U.X - K_d.X \qquad (1)$$

$$\frac{ds}{dt} = \frac{Q}{Vb}.So - \frac{Q}{Vb}.\mathrm{Se} - \frac{\mathrm{UX}}{Y} \qquad (2)$$

Where Q is the flow rate of influent wastewater ($L.d^{-1}$), V_b is the volume of sludge bed (L), X_o is the biomass concentration of influent wastewater ($mg1^{-1}$), X_e is the biomass concentration of effluent wastewater ($mg1^{-1}$), X is the biomass concentration in reactor ($mg1^{-1}$), K_d is the endogenous decay coefficient (d^{-1}), S_o is the influent substrate concentration ($mg1^{-1}$), S_e is the effluent substrate concentration ($mg1^{-1}$), μ is the specific growth rate (d^{-1}), μ_m= maximum specific growth rate (d^{-1}) and Y is the yield coefficient.

The ratio of total biomass in the reactor to biomass wasted per given time correspond to the average time called SRT or referred as mean cell residence time (θc) and calculated from Eq. (3)

$$\theta c = \frac{Vb.X}{Q.Xe} \qquad (3)$$

The relationship between specific growth rate and limiting substrate concentration can be expressed by Monod Eq. (4) as

$$\mu = \frac{\mu m.Se}{Ks+Se} \qquad (4)$$

The constant μ_m indicates maximum growth rate of microorganisms when the substrate is being used at its maximum rate, and Ks indicates the level of substrate concentration at one half the specific substrate utilization rate.
By considering Xo is negligible and $\frac{dx}{dt} = 0$, the biomass concentration (X) in the reactor can be derived from Eqs. (1)- (4) as follows:

$$\frac{Q}{Vb} Xe = X\,(U - Kd) \qquad (5)$$

By substituting Eq. (3) in Eq. (5), So μ will be

$$\mu = \frac{1+\theta c.Kd}{\theta c} \qquad (6)$$

Also from equation (2) by considering $\frac{ds}{dt} = 0$ and using Eqs. (5) and (6) then

$$X = \frac{QY\theta c}{Vb\,(1+Kd\theta c)} (So - Se) \qquad (7)$$

Also the substrate concentration (S) can be derived from Eq.(2) as follows:

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$$\frac{Q}{Vb}(Se - So) = \frac{UX}{Y} \qquad (8)$$

Where Y is defined as yield coefficient.

From Eqs (4) and (8) we get equation [9]

$$\frac{Q}{Vb}(So - S) = \frac{Um.Se}{Ks+Se} \cdot \frac{X}{Y} \qquad (9)$$

And from equation (7) and (9) we get

$$Se = \frac{Ks.(1+Kd\theta c)}{\theta c.(Um-Kd)-1} \qquad (10)$$

Eq. (7) and (10) are nonlinear equations, so to estimate the values of the kinetic constants, an arrangement of Eqs (4) and (7) will result Eq. (11) and (12)

$$\frac{X\theta c}{So-Se} = \frac{KSY}{Um} \cdot \frac{1}{Se} + \frac{Y}{Um} \qquad (11)$$

$$\frac{So-Se}{X} = \frac{Kd}{Y} . \theta c + \frac{1}{Y} \qquad (12)$$

B. Haldane Model

The Haldane kinetics follows the equation as stated in Eq. 13[16] .

$$U = \frac{Um}{1+\frac{Ks}{Se}+\frac{Se}{Ki}} \qquad (13)$$

Where K_i indicates the substrate concentration, above which growth rate of microorganisms is less than $\frac{Um}{2}$ indicating inhibition effect. At steady-state conditions, after applying substrate balance in UASB reactor, Eq.(14) can be obtained

$$\frac{Vb.Se.X}{Q.(S0-Se)} = \frac{(Se)^2}{Ki.K} + \frac{Se}{k} + \frac{Ks}{K} \qquad (14)$$

Where $K = \frac{Um}{Y}$, the maximum specific substrate utilization rate.

C. Contois Model

Contois kinetic is another mode with slight modification of Monod model to calculate the substrate growth rate

$$U = \frac{Um\ S}{KxX+S} \qquad (15)$$

Where µ is the specific growth rate, Kx is the Contois constant. The selective substrate concentration is proportionally related to the cell growth where U is inversely related to the cell growth rate at high cell density

D. Chen&Hashimoto Model

Among the kinetic models developed to understand the performance of anaerobic digestion of the retting wastewater studied is one proposed by Chen and Hashimoto. Its main characteristics are: (a) the specific growth rate of microorganisms µm, is defined from the Contois' equation; (b) continuous or semi continuous completely mixed flow systems are considered; (c) predominant microorganisms in the biological treatment system are not present in the influent; (d) the yield coefficient (ratio of the cell mass concentration divided by the substrate concentration) is constant; (e) cellular lysis is not taken into account; (f) effluent substrate concentration is directly proportional to influent substrate concentration; (g) methane production is directly proportional to biodegradable substrate assimilation, and methane and carbon dioxide are the main final

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products of organic matter biodegradation. The kinetic equation governing this anaerobic digestion model is given by

$$\Theta = 1/\mu_m + K/\ \mu_m * \beta / (\beta_0 - \beta) \quad (16)$$

Where B denotes the volume (liters) of methane produced under normal conditions of pressure and temperature per gram of substrate (COD) added to the digester (l CH_4 STP/g COD $_{added}$); B_0 is the volume of methane produced under normal conditions of pressure and temperature per gram of substrate added at infinite retention time or for complete utilization of substrate (l CH_4 STP/g COD_{added}); m_{max}, is the maximum specific microbial growth rate (days^{-1}); K, is a dimensionless kinetic parameter related to the rate and the stability of the anaerobic process [17]; and Θ is the HRT (days).

III. MATERIALS AND METHODS

Flax retting wastewater resulted from Tanta Company for oil and flax, Egypt was treated an aerobically by using continuous UASB reactor. The experimental methodology including acclimation step, feed preparation and characteristics, seed sludge, equipments, sample collection, chemical analyses, reactor configuration, gas collection system, and other technical and operational details was fully documented in the author's previous studies on the anaerobic treatability of flax retting wastewater [3] within six average results of 15 experiments under steady conditions which are used in the present kinetic study to determine the kinetic coefficients (μ_m , K_s , K_d, Y) .

IV. RESULTS AND DISCUSSION

A. Monod Model

In this article, Monod Model is tested for its capability to demonstrate the substrate removal (degradation of organic substances) and microorganism's growth rate kinetics of UASB reactor in treating Retting wastewater with COD ranging from 3.570- 4.280 g/L.

The Y and K_d values calculated from Eq.(12)by plotting HRT (θ) versus $\frac{So-Se}{X}$ as illustrated in Fig. (1) Where the slop represents $\frac{Kd}{Y}$ and the intercept represents $\frac{1}{Y}$.

The Y and K_d values are 0.74 gm VSS/gm COD and 0.2 d^{-1} respectively. The Y is higher than that reported for acetoclastic methogens (0.01-0.05 mg VSS/ mg COD) and in the range of acidogens (0.14-0.17 mg VSS/ mg COD) [18]. This is due to the determination of overall yield for mixed culture. Also the value of Y is high (0.083 mg VSS/ mg COD) as compared with wastewater of COD ranging from 0.300-4.000 g/L [1]. The magnitude of endogenous decay coefficient (K_d) observed is high as compared within the range reported for acetoclastic methogens (0.0004-0.007 h^{-1}) [18].

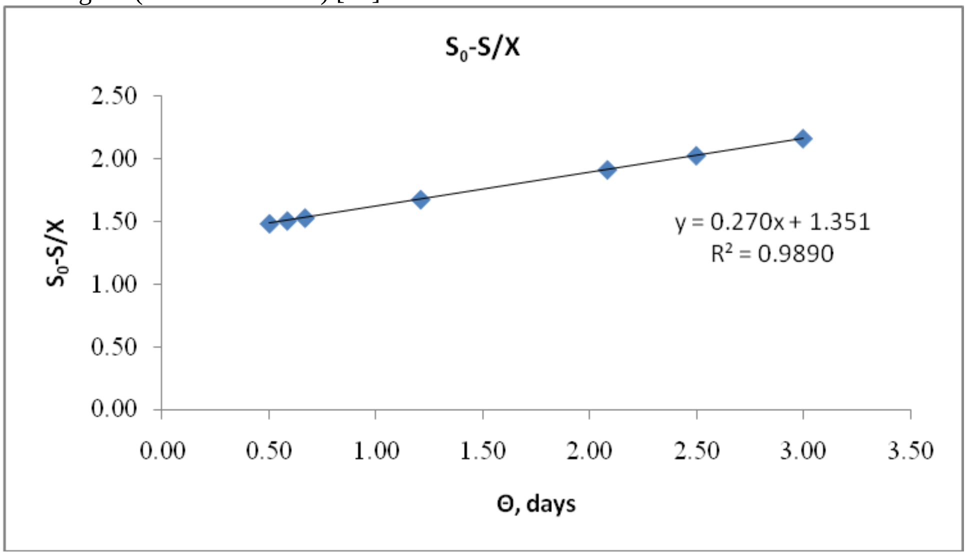

Fig. 1 The calculation of Y and Kd values

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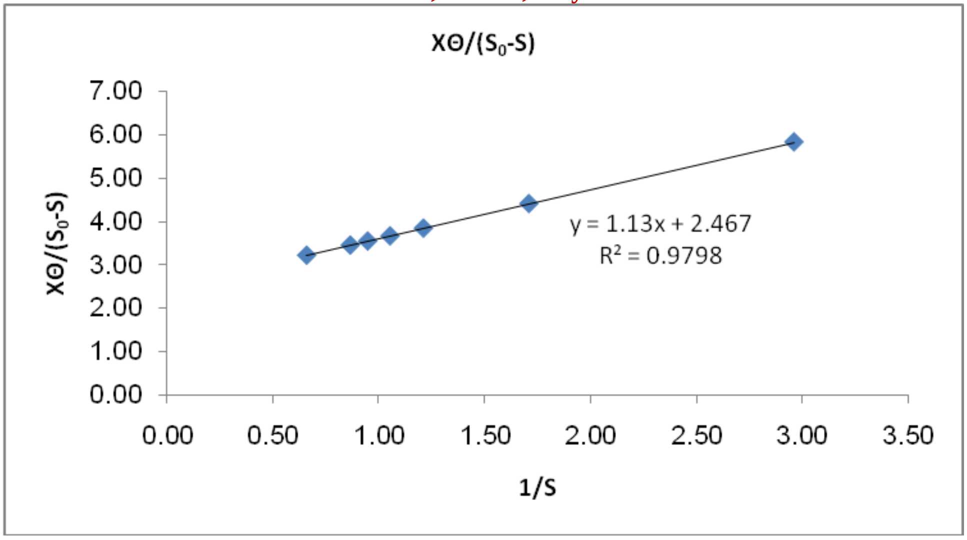

Fig. 2 Determination of the values of µm and Ks

The values of μ_m and K_s were determined from Fig [2] using Eq. [11] by plotting $\frac{X\theta c}{So-Se}$ verses 1/Se. The μ_m is 0. 3 d^{-1} and Ks 450 gm COD/L. The obtained μ_m is at a side of that reported for mixed and pure cultures of acetoclastic methogens at temperature 35-37 °C [18-20].

B. Haldane Model

$$\frac{Vb.Se.X}{Q.(S0-Se)} = \frac{(Se)^2}{Ki.K} + \frac{Se}{k} + \frac{Ks}{K} \qquad (14)$$

$$\frac{1}{Ki.K} = 0.00257$$

$$\frac{1}{k} = 2.47$$

$$\frac{Ks}{K} = 1125$$

From Eq. (14) a plotting of $\frac{Vb.Se.X}{Q.(S0-Se)}$ versus Se is presented in Fig (3) to calculate $\frac{1}{Ki.K}$, $\frac{1}{k}$ and $\frac{Ks}{K}$ where $\frac{1}{Ki.K}$ = 0.00257, $\frac{1}{k}$ = 2.47 and $\frac{Ks}{K}$ = 1125

By solving these three equation with the three unknown K is 0.45, Ks is 450 mg COD/l and K_i is 950mg COD/l

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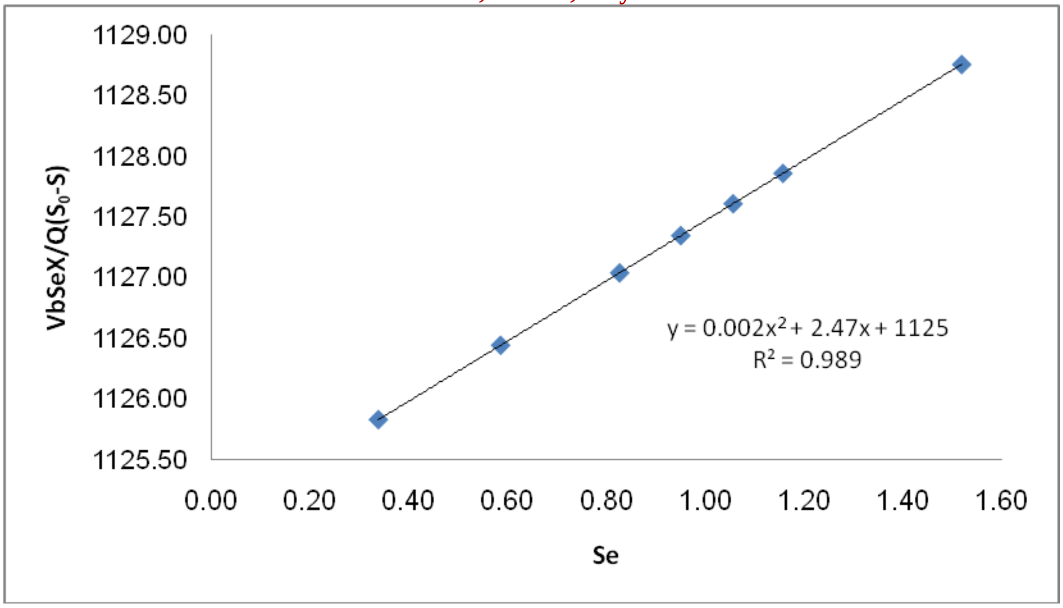

Fig. 3 Determination of kinetic parameters of Haldane model

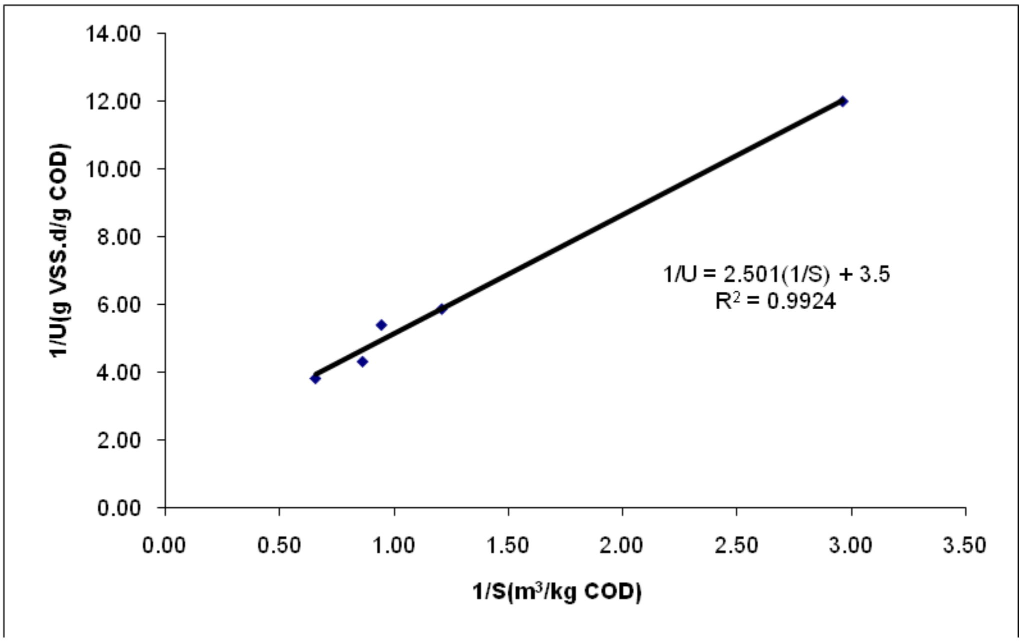

Fig. 4 Modified Monod Model

C. Substrate Utilization rates for modified equation of Monod, Contois and Chen &Hashimoto

The kinetic coefficients of the selected model were derived from Eq. (2) in Table (1) by using a linear relationship. The coefficients are summarized in Table (2). It was found that the three models produced a good relationship with $R_2 > 96\%$ for the UASB reactor treating retting wastewater as shown in Figures. 4,5 and 6. The better performance of both Contois and Chen & Hashimoto implied that organic loadings should be taken into consideration for digester performance. In fact these two models suggested that the predicted permeate COD concentration (S) is a function of influent COD concentration (So). However, in Monod model, S is independent of So. The excellent fitting of these three models ($R^2 > 96\%$) in this study suggests that the UASB reactor process is able to sustain loadings between 1.5 and 8.6 kg COD/m^3/d.

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Table (1) Mathematical expressions of specifics substrate utilization rates for known kinetic models

Kinetic Model	Equation 1	Equation 2
Monod	$U=kS/K_S+S$	$1/U=K_S/k(1/S)+1/k$
Contois	$U=U_{max}S/Y(BX+S)$	$1/U=a\ X/\mu_{max}+Y(1+a)/\mu_{max}$
Chen & Hashimoto	$U=\mu_{max}S/YKS_0+(1-K)SY$	$1/U=YKS_0/\mu_{max}+Y(1-K)/\mu_{max}$

Table (2) Results of the application of three known substrate utilization models

Model	Equation	R^2 (%)
Monod	$U^{-1}=2.501S^{-1}+3.595$ $K_S=560$ $K=0.3$ $\mu_{max}=0.259$	99.24
Contois	$U^{-1}=0.307X/S+2.82$ $B=0.1121$ $U_{max}=0.324$ $a=0.114$ $K=0.523$ $\mu_{max}=0.352$	96.16
Chen & Hashimoto	$U^{-1}=0.0189S_0/S+3.67$ $k=0.354$ $a=0.005$ $K=0.006$ $\mu_{max}=0.285$	98.96

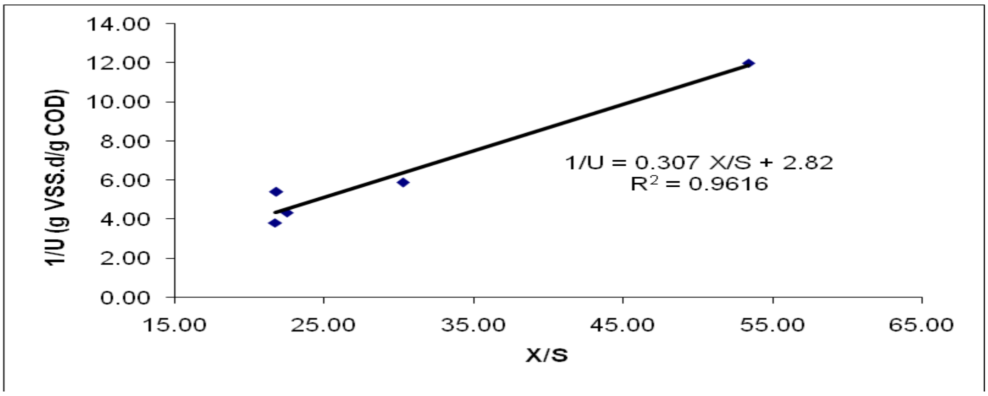

Fig. 5 Contois Model

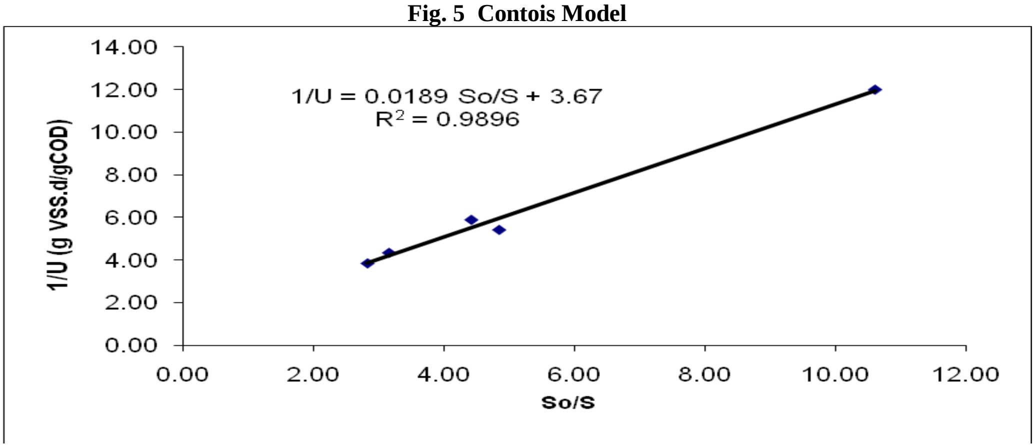

Fig. 6 Chen and Hashimoto Model

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V. CONCLUSION

In this study the kinetics of UASB reactor treating wastewater with COD in the range of 3000–4200 mg/ l has been explored using Monod model and Haldane model. The results of this analysis indicate that substrate removal model fits well for estimates of kinetic coefficients in UASB reactors. Among the three kinetic models, Monod model is observed to be the preeminent The other two models for predicting the performance of UASB reactors. It is also observed that linearized form of Contois and Chen &Hishimoto models engross considerable coefficient kinetic values compared to literature. The observed values of kinetic coefficients of linearized Monod model are in good agreement with reported values in literature. The growth yield coefficient, Y, was found to be 0.74 gVSS/gCOD while the specific microorganism decay rate was 0.20 d^{-1}. The k values were in the range of 0.3 – 0.523 gCOD/gVSS/d and μ_{max} values were between 0.259 and 0.352 d^{-1}.

VI. ABBREVIATIONS

Q = the flow rate of influent wastewater ($L.d^{-1}$)
V_b = volume of sludge bed (L)
X_o= biomass concentration of influent wastewater ($mg1^{-1}$)
X_e= biomass concentration of effluent wastewater ($mg1^{-1}$)
X= biomass concentration in reactor ($mg1^{-1}$)
K_d= endogenous decay coefficient (d^{-1})
S_o= influent substrate concentration ($mg1^{-1}$)
S_e= effluent substrate concentration ($mg1^{-1}$)
μ= specific growth rate (d^{-1})
μ_m= maximum specific growth rate (d^{-1})

REFERENCES

[1] Puspendu, B, Ghangreker, M.M., (2008).Analysis, evaluation, and optimization of kinetic parameters for performance appraisal and design of UASB reactors.Biosource technology. J., 99, pp 2132-2140.

[2] Okpokwasili, G.C., Nweke, C.O. (2005). Microbial growth and substrate utilization kinetics. African Journal of Biotechnology vol. 5 (4), pp. 305-317.

[3] Azza Hafez, Maaly Khedr and Randa Osman (2012). Flax Retting Wastewater Part 1: Anaerobic Treatment By Using UASB Reactor, Natural Resources Journal, Volume 7, No.3, pp.191-200.

[4] Batstone, D. J., Keller, J., Angelidaki, I., Kalyuzhnyi, S. V., Pavlostathis, S. G., Rozzi, A., et al. (2002). The IWA anaerobic digestion models no 1 (ADM1). Water Science and Technology, 45(10), 65-73.

[5] Batstone, D. J., Keller, J., Newell, R. B., & Newland, M. (2000a). Modeling anaerobic degradation of complex wastewater. I: model development. Bioresource Technology, 75(1), 67-74.

[6] Batstone, D. J., & Keller, J. (2003). Industrial applications of the IWA anaerobic digestion model no. 1 (ADM1). Water Science and Technology, 47(12), 199-206.

[7] Batstone, D. J., Keller, J., Newell, R. B., & Newland, M. (2000b). Modeling anaerobic degradation of complex wastewater. II: parameter estimation and validation using slaughterhouse effluent. Bioresource Technology, 75(1), 75-85.

[8] Shang, Y., Johnson, B. R., & Sieger, R. (2005). Application of the IWA anaerobic digestion model (ADM1) for simulating full-scale anaerobic sewage sludge digestion. Water Science and Technology, 52(1-2), 487-492.

[9] Beltran, J., Gonzalez, T., & Garcia, J. (2008). Kinetics of the biodegradation of green table olive wastewaters by aerobic and anaerobic treatments. Journal of Hazardous Materials, 154(1-3), 839-845.

[10] Bhunia, P., & Ghangrekar, M. M. (2008).Analysis, evaluation, and optimization of kinetic parameters for performance appraisal and design of UASB reactors. Bioresource Technology, 99(7), 2132-2140.

[11] Sosnowski, P., Klepacz-Smolka, A., Kaczorek, K., & Ledakowicz, S. (2008).Kinetic investigations of methane co-fermentation of sewage sludge and organic fraction of municipal solid wastes. Bioresource Technology, 99(13), 5731-5737.

[12] Vavilin, V. A., Fernandez, B., Palatsi, J., & Flotats, X. (2008). Hydrolysis kinetics in anaerobic degradation of particulate organic material: an overview. Waste Management, 28(6), 939-951.

[13] Garcı´a-Ochoa, F., Santos, V. E., Naval, L., Guardiola, E., & Lo´ pez, B.(1999). Kinetic model for anaerobic digestion of livestock manure. Enzyme and Microbial Technology, 25(1-2), 55-60.

[14] Ponsa´ , S., Gea, T., & Sa´nchez, A. (2011). Anaerobic co-digestion of the organic fraction of municipal solid waste with several pure organic co-substrates. Biosystems Engineering, 108(4), 352-360.

[15] Siles, J. A., Martin, M. A., Chica, A., & Borja, R. (2008). Kinetic modeling of the anaerobic digestion of wastewater derived from the pressing of orange rind produced in orange juice manufacturing. Chemical Engineering Journal, 140(1-3), 145-156.

[16] Versyck, J.K., Claes, E.J., van Impe, F.J., (1997). Practical identification of unstructured growth kinetics by application of optimal experimental design. Biotechnol. Prog. 13, 524–531.

[17] A.M. Jime´neza, R. Borjab,_, A. Martı´nc, F. Raposo, (2006) " Kinetic analysis of the anaerobic digestion of untreated vinasses and vinasses previously treated with Penicillium decumbens", Journal of Environmental Management, 80,pp. 303–310.

[18] Pavlostathis, S.G., Giraldo- Gomez, E., (1991).Kinetics of anaerobic treatment. Water Sci. Tehnol.24,pp. 35-59.

[19] Lokshina, L.Y., Vaviline, V.A., Ketunen, R.H., Rintala, J.A., Hollinger, C., Nozhevnikove, NA., (2001). Evaluation of kinetic coefficient using integrated Monode and Halden Models for low temperature acetoclastic methanogenesis, Water Res. 35, pp.2913-2922.

[20] Fukuzaki. N.N., Nagi., S (1990) kinetic of the methanogenic fermentation of acetate. Appl.Environ. Microbiol, 56,pp. 3158 – 3163.

AUTHOR BIOGRAPHY

Randa M.Osman is an Assistant Professor in Chemical Engineering Department and Pilot Plant Laboratories, National Research Center, Dokki, Cairo, Egypt. She has a Professional Experience in the Fields of Biogas Technology, Wastewater Treatment, Chemical and Biochemical Instrumental Analysis and Computer Aided Design. She has more than15 international publications.

Azza I.Hafez is the former Head of Engineering Research Division, National Research Center, Cairo and her Present Position is Emeritus Professor in Chemical Engineering Department and Pilot Plant Laboratories, National Research Center, Dokki, Cairo, Egypt. Her research interest is:

a) Water & Wastewater Treatment Plants Study, Process Design and Supervision.
b) Water Desalination, Plants Study, Process Design and Supervision.
c) Membrane Desalination.
d) Plants (Seawater & Brackish) Study, Process Design and Supervision.
e) Membrane Separation.
f) Environmental Research & Pollution -Control Consultation.
g) Preparation of the Environmental Impact Assessment (EIA) Document.
h) Industrial Chemicals Manufacturing Feasibility.
i) Process Development, Chemical Engineering and Plant Design.
j) Nanoparticle Ion Exchange Resins Preparation.
k) Feasibility Studies.

Maaly A.Khedr is Emeritus Professor in Chemical Engineering Department and Pilot Plant Laboratories, National Research Center, Dokki, Cairo, Egypt. She has a list of activity in the field of Water & Wastewater Treatment Plants Study, Process Design and Supervision. Water Desalination, Plants Study, Process Design and Supervision. Membrane Desalination. Membrane Separation. She has a numerous number of international publications in the field of wastewater treatment methods. Her recent publications are devoted to wastes management.