RESEARCH ARTICLE

• Arch Hyg Sci 2013;2(3):108-113
• Journal Homepage: http://jhygiene.muq.ac.ir

Study of Kinetic coefficients of a Membrane Bioreactor (MBR) for municipal wastewater treatment

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A-R-T-I-C-L-E I-N-F-O

Article Notes:
Received: Oct 3, 2013
Received in revised form: November 12, 2013
Accepted: November 16, 2013
Available Online: November 22, 2013

Keywords:
Biokinetic coefficient
Membrane bioreactor
municipal wastewater

A-B-S-T-R-A-C-T

Background & Aims of the Study: In order to design membrane bioreactors (MBR) properly, it is essential to comprehend the behavior of microorganisms in such wastewater treatment processes.

Materials & Methods: In this study, a lab-scale MBR process was operated to determine the biokinetic coefficients of the MBR system under different MLSS concentrations of 6800, 7000, 7400, and 7800 mg/l and organic loading rates of 0.5 kg COD/m^3/day.

Results: The results of this study showed that the yield of microorganisms (Y), the endogenous decay coefficient (k_d), the maximum specific growth rate (μ_{max}) and the saturation constant (K_s) were in the range of 0.67 g VSS/g COD, 0.56 d^{-1}, 1.86 d^{-1} and 6.65 mg COD/l, respectively.

Conclusions: The kinetic coefficients in this study can be used to improve the operation and design the MBR system in full scale.

Please cite this article as: Ali Naghizadeh*, Elham Derakhshani, Ahmad Reza Yari, Study of Kinetic coefficients of a Membrane Bioreactor (MBR) for municipal wastewater treatment. Arch Hyg Sci 2013;2(3):108-113.

Background

The membrane bioreactor (MBR) is a system that combines biological treatment with membrane filtration into a single process. The first application of MBR technology was reported in 1969, when an ultrafiltration membrane was used to separate activated sludge from the final effluent of a biological wastewater treatment system and the sludge was recycled back into the aeration tank (1).

Submerged membrane bioreactors are increasingly used for domestic wastewater treatment, and there is a growing need to provide valuable modeling tools for their design and operation.

In the years ago, the biological wastewater treatment processes design was based on the parameters such as hydraulic loading, organic loading, and detention time. Today, the design utilizes empirical and rational parameters based on biological kinetic equations. These equations describe growth of biological solids, substrate utilization rates, food-to-microorganisms ratio, and the mean cell residence time. Reactor volume, substrate utilization, biomass growth, and effluent quality can be calculated from those equations. Biokinetic coefficients of

different wastewater treatment processes were evaluated by several investigators (2,3).

However, kinetic coefficients used in the design of activated sludge processes include specific growth rate (μ), maximum rate of substrate utilization per unit mass of microorganisms (k), half-velocity constant, or substrate concentration at one-half the maximum specific growth rate (K_s), maximum cell yield (Y), and endogenous decay coefficient (k_d). Typical values of kinetic coefficients for activated sludge are shown in Table 1 (4).

Table 1) Typical values of kinetic coefficients for activated sludge process

Coefficient	Basis	Value	
		Range	Typical
k ($k=\mu_{max}/Y$)	day^{-1}	2–8	4
k_d	day^{-1}	0.03–0.07	0.05
K_s	mg/l, BOD_5	40–120	80
	mg/l, COD	20–80	40
Y	VSS/BOD_5	0.3–0.7	0.5
	VSS/COD	0.2–0.5	0.4

The initial activated sludge system has been widely studied previously, leading to complete kinetic knowledge for modeling the main heterotrophic and autotrophic biological processes (5).

Many of the studies are focused on the operational stability and usefulness of MBR for treating various wastewaters under different operating conditions (6, 7).

Little has been found reported on the kinetic properties of the MBR process which are important in understanding the mechanism of the MBR process and in designing and controlling the system.

Aims of the study: The purpose of this paper was to study the kinetic properties of the MBR system when it is applied to urban wastewater treatment.

Materials & Methods

Composition of Synthetic Wastewater (SWW) and operational conditions:

A synthetic substrate was prepared based on the COD: N: P ratio 100: 5:1. Glucose, NH_4Cl and KH_2PO_4 were used as sources of carbon, nitrogen and phosphorus, respectively. The synthetic wastewater used in this study simulates municipal wastewater. It has been designed to provide all the inorganics and micronutrients, as well as nitrogen, phosphorous for the development of the biomass. The influent substrate concentration was fixed to 500 mg/l COD for the biokinetic studies.

The list of operational conditions is presented in Table 2. The MBR system was operated with a flow rate of 96 L/d. The hydraulic retention times (HRTs) of anoxic tank and oxic tank were 2.6 and 12 hours, respectively.

Membrane Cleaning:

Membrane fabric cleaning was achieved by combination of various methods including intermittent pumping of the suction pump, continuous air scouring by air from stone aerators in the reactor, back washing with water, back washing with air and mechanical cleaning of the membrane fabric with a brush. Technical data for membrane is presented in Table 3.

Analytical Procedures:

For the continuous reactor experiments, the sampling from the reactor and permeate were carried out periodically and analyzed for the following Physio-chemical parameters, by the methods described in the Standard Methods for the examination of wastewater (8).

Model description:

The purpose of studying the kinetic coefficients was to obtain information on the rate of cell growth and consumption of substrate.

Table 2) Operating conditions of the submerged MBR

Parameters	UNIT	Run 1	Run 2	Run 3	Run 4
Influent flow	L/d	90	120	200	288
HRT	h	12.8	9.6	5.8	4
SRT	day	17	10	6	3
MLSS	g/L	7.8	7.4	7.09	6.8
MLVSS	g/L	5.8	5.6	5.4	5.3
Waste sludge	L/d	4.8	2.4	1.2	0.6
OLR	Kg COD/m3.d	0.5	0.5	0.5	0.5
Mixed liquor recycle	%	2.5Q	2.5Q	2.5Q	2.5Q

*HRT – hydraulic retention time * OLR- Organic loading rate

*The amount of MLSS and MLVSS are based on arithmetic mean in each run

Table 3) Specifications of hollow fiber membrane

Physical property	Specifications
Raw material	polypropylene
Inside diameter (µm)	320
Pore size (µm)	0.1
Pore density (%)	40-50

This enabled the required volume of the reactor to be calculated and simulation of the system can be used for process control. The kinetic coefficients of a biological system have generally been determined experimentally using either continuous flow, completely mixed or batch lab-scale reactors. For soluble substrate, the substrate utilization rate in biological systems can be modeled with the following expression (9):

$$r_{su} = -\frac{dS}{dt} = \frac{kSX}{K_s + S} \qquad (1)$$

The biomass growth rate is proportional to the substrate utilization rate by the yield coefficient, and the biomass decay is proportional to the amount of biomass present. When the substrate is being consumed at its maximum rate, the bacterial growth rate is also at its maximum (10). By substituting ($k=\mu_{max}/Y$) in Eq. (1), we will have:

$$r_{su} = \frac{\mu_{max} XS}{Y(K_s + S)} \qquad (2)$$

Taking into consideration influent and effluent substrate concentration:

$$Q_0 S_0 = QS + \frac{1}{Y}\left(\frac{\mu_{max} XS}{K_s + S}\right)V \qquad (3)$$

And also,

$$r_g = \frac{dx}{dt} = -Y\left(\frac{ds}{dt}\right) - kdX = Y\left(\frac{kXS}{K_s + S}\right) \qquad (4)$$

Dividing both sides of Eq. (4) by the biomass concentration X, we obtain the specific growth rate as:

$$\frac{r_g}{X} = \mu = Y\left(\frac{K_s}{K_s + S}\right) - k_d \qquad (5)$$

The specific biomass growth rate (µ) can be defined as inverse of the solid retention time (SRT).

$$\frac{1}{SRT} = (Q - Q_w)X_e + \frac{Q_w X_w}{VX} \qquad (6)$$

Thus, Eq. (4) can be rearranged as follows:

$$\frac{1}{SRT} = -Y\left(\frac{r_{su}}{X}\right) - k_d = \frac{YQ(S_0 - S)}{VX} - k_d \qquad (7)$$

Results

A summary of the results at the steady state conditions as well as kinetic coefficients obtained from the continuous system studies is present in Table 4 and 5 respectively.

The plot for determination of non biodegradable soluble COD is shown in Figure 1. Fig 2 and 3 show the curves of the biokinetic determination.

Table4) Experimental parameters values in 4 runs

Run number	Influent COD (mg/l)	Effluent COD (mg/l)	Non biodegradable COD (mg/l)	Biodegradable COD (mg/l)	$1/S_e$ (l/mg)	1/SRT (day^{-1})	$\frac{Q(S_0 - S_e)}{VX}$	$\frac{VX}{Q(S_0 - S_e)}$
Run 1	500	5	0.98	3.8	0.25	0.059	0.16	6.31
Run 2	500	8	0.98	7	0.14	0.1	0.22	4.57
Run 3	500	10.4	0.98	9.5	0.1	0.17	0.38	2.64
Run 4	500	14	0.98	13	0.07	0.34	0.55	1.82

Table 5) Summary of biokinetic coefficient for membrane bio reactor

Type of study	Y (mg/mg)	k_d (day)$^{-1}$	μ_m (day)$^{-1}$	K_s (mgCOD/l)
►**This study**	0.67	0.056	1.86	6.65
CF-MBR	0.276	0.07	0.653	62.3
Municipal wastewater	0.4-0.8	0.025-0.48	2-5.18	11-3720
Industrial wastewater	0.3-0.72	0.045	0.77	5.08

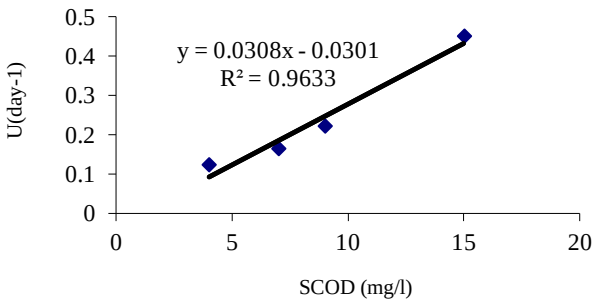

Fig. 1) determination of non biodegradable soluble COD

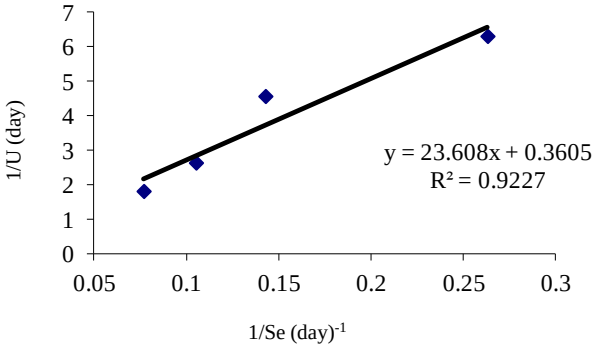

Fig. 2) Determination of K and K_s biokinetic coefficients

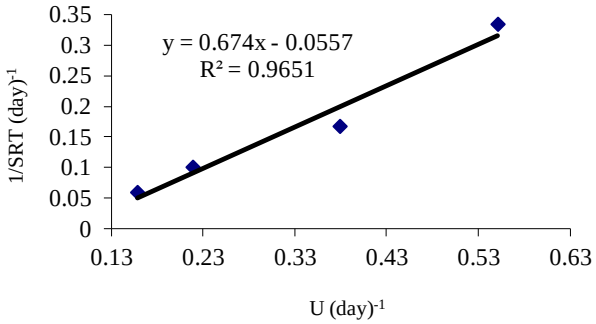

Fig. 3) Determination of Y and K_d biokinetic coefficients

Discussion

In continuous flow completely mixed reactor, the determination of the kinetic coefficients is usually achieved by collecting data from lab-scale or pilot-plant experiments. Operating the system at various hydraulic retention times (HRT) and/or at various sludge retention times, and by allowing (at each adapted stage or HRT or SRT), a steady state condition to prevail. Accurate measurements of the biomass and permeate substrate concentration are then recorded. The parameters such as K_s, μ, Y and k_d can be determined through linearization of equation 5 as follows:

$$\frac{Q}{VX}(S_0 - S) = \frac{1}{Y}\frac{1}{SRT} + \frac{k_d}{Y} \qquad (8)$$

To determine the kinetic coefficients, µm and Ks, equation 6 can be re arranged as:

$$\frac{SRT}{1+(SRT\ k_d)} = \frac{K_s}{\mu_m}\left(\frac{1}{S}\right) + \frac{1}{\mu_m} \qquad (9)$$

If equation 8 is plotted as $Q(S_0\text{-}S)/VX$ versus 1/SRT, then from the slope and the intercept, it is possible to determine, the kinetic coefficients, k_d and Y. Substituting the obtained value of k_d in equation 9 and plotting $SRT/[1+(SRT\ k_d)]$ versus 1/S, then from the slope and the intercept it is possible to determine, the kinetic coefficients, µm and K_s.

A summary of the results at the steady state conditions as well as kinetic coefficients obtained from the continuous system studies is presented in table 4 and 5 respectively. It appears that the kinetic coefficients vary significantly with the change in MLSS concentration. However, this variability does not follow any definite pattern, and is not straight forward to draw a firm conclusion. This variability might be attributed to the nature of the system itself, since the system could be a selective process and the kinetic coefficients obtained might represent a different species. These finding are in accordance with *Henze et al.* (11).

The plot for determination of non biodegradable soluble COD is shown in figure 1. As can be seen in this figure non biodegradable COD which is the interval between interception of the curve and the X axis is 0.98 mg/L. this result is similar with the results of *Rahman* and *Al-Malack* (12).

Fig 2 and 3 show the curves for determination of the biokientic determination. According to Fig 2 and from the slope and the intercept it is possible to determine, the kinetic coefficients, K and K_s. table 2 show amount of these parameters. From the slope and the intercept of the curve presented in Fig 3, the biokinetic of Y and k_d can be determined.

Generally, the values of the kinetic coefficients which are presented in table 2 are within the normal range for the activated sludge process, but the values of K_s, especially for MLSS of 7400 mg/l are much higher than those reported in the literature. The estimation of the K_s value is affected by an estimation of the decay rate, k_d, thus any uncertainty in estimating k_d will be reflected in K_s. Y values were within the range of reported values treating glucose based synthetic wastewaters. However, Y values were lower than upper rage that for industrial plants treating the industrial wastewaters. This clearly shows that type of substrate has a role to play in the kinetic coefficients. These results are agreement with finding of *Wisniewski et al*. (13).

Conclusion

Kinetic analysis of the MBR system was successfully performed using different MLSS concentration. As a result of this study the biokinetic coefficients of MBR were similar to activated sludge process. According to this study Y, k_d, μ_{max}, and K_s coefficients were found to be 0.67 g VSS/g COD, 0.56 d^{-1}, 1.86 d^{-1} and 6.65 mg COD/l, respectively. The kinetic parameters determined in this study can be used to improve the design and operation of the MBR system on full scale.

Footnotes

Conflict of Interest:

The authors declare no conflict of interest.

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