Determination of the Biological Kinetics for Diyala River at Al-Rustimiyah WWTP's

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Abstract

Activated sludge process is considered one of the most common and highly effective methods used in aerobically biological treatment systems. The design of such systems is usually based on the biological kinetic approach considerations. The present study is concerned in determining the biological kinetic of the last part of Diyala River at AL-Rustimiyah WWTP's, Baghdad, Iraq. A completely mixed continuous flow lab-scale reactor without recycling was used for this purpose. Various detention times were adopted during the experimental work ranging from 0.723 to 3.809 days. Influent and effluent BOD_5, MLVSS and MLSS for the aeration tank, among other tests were performed at different detention times, after reaching the steady state conditions, in order to generate the required data for bio-kinetic coefficients. The biological kinetics k, Y, K_d, and K_s for the last part of Diyala River at AL-Rustimiyah WWTP's were found to be 5.68 d^{-1}, 0.75, 0.06 d^{-1}, and 70 mg/l, respectively. These values were compared with the bio-kinetics of different types of wastes and were found to be within the typical ranges of bio-kinetic parameters for activated sludge process treating domestic wastewater, which indicates that the water at the river reach of interest is rather wastewater than pure river water.

Key Words: Biological Kinetics, Diyala River, Biological Oxygen Demand (BOD), Activated Sludge, Experimental setup

حساب محددات الحركة البايولوجية لنهر ديالى مقابل محطات معالجة المياه الثقيلة في الرستمية

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الخلاصة

تعتبر طريقة الحمأة المنشطة احدى اهم الطرق واكثرها شيوعا واستخداما في انظمة المعالجات البايولوجية الهوائية، وتصميم هكذا انظمة يأخذ بنظر الاعتبار قيم محددات الحركة البايولوجية للمياه المعالجة. تهتم الدراسة الحالية بحساب قيم محددات الحركة البايولوجية للجزء الاخير من نهر ديالى مقابل محطات معالجة المياه الثقيلة في الرستمية، بغداد، العراق. تم استخدام مفاعل مختبري ذو تصريف مستمر وبدون ارجاع لهذا الغرض،كما وتم اعتماد عدة ازمان للمكوث خلال التجارب العملية تتراوح بين 0.723 و 3.809 يوم. تم اجراء عدة فحوص للمياه الداخلة والخارجة من المفاعل منها: MLSS, MLVSS ,BOD_5 وغيرها. هذه الفحوص تم اجراءها بعد الوصول الى حالة الاستقرار للمفاعل وتم تكرارها لكل زمن مكوث. بالاعتماد على هذه الفحوص، تم استخراج محددات الحركة البايولوجية للجزء الاخير من نهر ديالى لتكون كالتالي: K_s=70mg/l ، K_d=0.06d^{-1} ، Y=0.75، k=5.68d^{-1} . عند مقارنة النتائج المستحصلة من هذا البحث مع نتائج سابقة لإنواع مختلفة من المخلفات، وجد انها تقع ضمن حدود محددات الحركة البايولوجية لمياه المجاري، مما يدل على ان مياه نهر ديالى في جزءه الاخير هو مياه ثقيلة اكثر مما هو مياه نهر نقية.

1. Introduction

One of the most important aspects in designing a biological treatment for any kind of wastewater is investigating the biological kinetics of that waste.

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Studying the kinetics of an aerobic biological treatment for example, yields the rate at which microorganisms degrade a particular waste, and by that providing the basic information required for sizing the biological reactor (Sharif, 1999).

The last part of Diyala River just before its confluence with the Tigris River in about 15 km, located opposite of AL-Rustimiyah WWTP's south of Baghdad, Iraq, was the concern of this study.

This segment of Diyala River was exposed to multiple points of treated and raw municipal waste water discharges. These were represented by the outfalls and bypass of three wastewater treatment plants (WWTP) of Al-Rustimiyah (Al-Samawi and Al-Hussaini, 2015). The WWTP's mentioned above were over loaded with influent that exceeds their operational capacities which in turn, affects the aquatic life of the receiving water body represented by Diyala River.

Literature has shown that the natural self - purification process of this part of the river water body was rather slow or absent due to the heavy pollution loads. It was concluded that full recovery of the river from pollution could only be possible via human intervention (Al-Samawi and Al-Hussaini, 2015). For that reason, it was essential to determine the biological kinetics for the river water, at the reach of interest, to help in designing a proper treatment for it.

No local references are available in literature for determining the biological kinetics of Diyala River. To this end, the present study was concerned in determining these biological kinetic.

2. Materials and Methods
The Experimental Setup

A completely mixed continuous flow reactor was operated in this study. No recycle was adopted in the system duo to the difficulty in controlling the recycling in a bench scale reactor (George et al., 2004). A picture and a schematic flow diagram of the biological reactor bench scale used in this study were shown in Figures 1:a&b.

As shown in Figure 1, four reactors were used in the biological process, each having a slight difference in their capacity in order to ensure different conditions in each reactor. Table 1 illustrates the dimensions and capacity of each reactor.
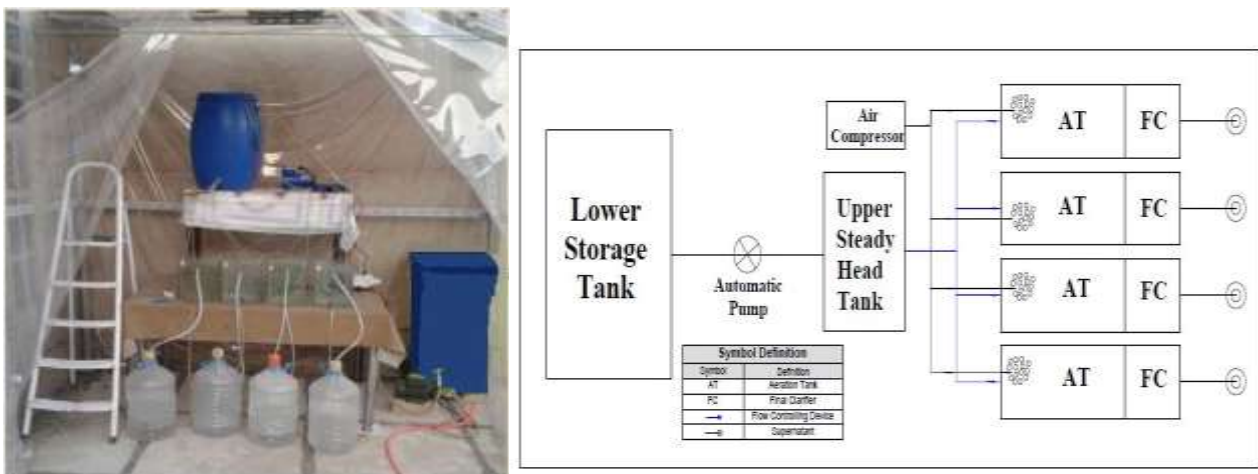

Figure 1.; a: Lab. exp. Setup   b: Schematic diagram of the exp. Setup

The components of the bench scale reactor used were as follows:

1- Lower storage tank.
2- Automatic pump.
3- Upper steady head tank.

4- Four reactors each contain an aeration tank and a final clarifier.
5- Aeration system.
6- Mixing system.
7- Effluent collecting tank.

Table 1: Dimensions and Capacities of the Reactors.

Reactor No.	Total Length, cm	Total Width, cm	Total Height, cm	Water Height, cm	AT* Length, cm	FC* Length, cm	AT Capacity, L	Total Capacity, L
1	28.3	19.3	25	20	18	10	6.948	10.9238
2	29.6	21	25	20	19	10.3	7.980	12.4320
3	29.1	19.4	24	20	18.8	10	7.294	11.2908
4	29.3	19.4	24.6	20	19	10	7.372	11.3684

* AT: Aeration Tank, FC: Final Clarifier.

Operational Procedure

The reactors in the experimental setup were seeded with activated sludge obtained from the recirculation pit of the most active reactors in AL-Rustimiyah WWTP. Gradual acclimation with the river water was done. The reactors were operated initially as batch systems for a period of three days in order to develop the biomass then switched to the continuous completely mixed flow system. The desired cell residence times, taken equal to the hydraulic detention times for this case, were adopted by controlling the flow rates of each reactor. Continuous observations were done to detect steady state conditions, denoted by constant BOD_5 values for effluent samples taken at different times and stably approaching to zero turbidity and suspended solids values for effluent samples. When steady state was reached, samples of in, out, and within the reactors were taken. Different measurements such as BOD, MLSS, MLVSS, and others were tested for each sample and applied to plots and equations. Table 2 shows different relations obtained in the reactor.

Table 2: Laboratory tests showing different relations in the reactor

Test No.	MLSS, mg/l	MLVSS, mg/l	MLVSS/MLSS %	BOD_5	COD	COD/BOD_5	SVI
1	268	215	80	114	182	1.56	150
2	423	368	87	210	351	1.67	129
3	410	361	88	290	415	1.43	131
4	378	310	82	140	230	1.64	139
5	331	282	85	309	464	1.50	147
6	304	241	79	277	465	1.68	152
Average	352	296	84	223	351	1.6	141

Experimental setup Monitoring

Controlling the environmental conditions should be necessary for any biological treatment (Mumtaz et al., 2012). During an entire experiment, continuous monitoring of DO, pH, ORP, and Temperature were conducted duo to their great affect on the biological process. Nitrogen, Phosphorus, and other parameters were tested as well.

Analytical Methods

All performed tests were carried out according to the APHA regulations (APHA, 2005).

Temperature

The temperature in the reactors fluctuated between 26 and 35 ℃, which lies within the convenient temperature range required for biological treatment by heterotrophs under aerobic conditions (Doetsch and Cook, 1973).

pH

The pH in the reactor was kept within the suitable range of (6.5- 8.5) for biological treatment (Wilkison, 1975).

DO

DO concentrations in the reactors were maintained between the ranges of (2.5 – 3.5) mg/l, which was also desirable for the biological treatment (Benefield and Randall, 1980).

ORP

The ORP was continuously monitored during work in order to verify the stage of treatment depending on the ORP range. The obtained range of ORP was (+32 to +77) mV, which classifies the treatment as cBOD degradation when compared to literature (YSI, 2008).

Nitrogen and Phosphorus

The presence of Nitrogen and Phosphorus in an aqueous solution indicates the amount of nutrients existing in it.

The (BOD:N:P) ratio was kept within the limit (100:5:1) (George et al., 2004). This was done by continuously testing random samples from influents and from the reactors for TN, PO_4, and BOD_5. The average ratio of (BOD:N:P) obtained during work was (114:9:2.3) that would be equal to (100:7.9:2).

3. Results and Discussion

The biological kinetic used in the design of any activated sludge process are:

The biomass yield (Y): defined as the ratio of the produced biomass to the consumed substrate (g biomass/g substrate) (George et al., 2004).

Endogenous decay coefficient (K_d): defined as the fraction of MLVSS oxidized per unit time during endogenous respiration process ($time^{-1}$) (Ramalho, 1983).

Maximum specific substrate utilization rate (k): defined as the maximum substrate utilized per unit mass of microorganism per day (George et al., 2004).

Half-Velocity constant (K_s): defined as the substrate concentration at one half the maximum specific substrate utilization rate, (mg/l) (George et al., 2004)**.**

The data used to determine the above kinetic were generated from the bench scale operates. Average values of X, S_o, and S corresponding to each detention time (θ) among others, are illustrated in Table 3.

Table 3 can be classified into two categories; the first representing the measured data during the experimental work, while the second defines the calculated data from equations with respect to the measured data.

Table 3: Average Laboratory data and related calculated data used to determine the Biological Kinetics.

Measured Data						
Reactor		Influent BOD$_5$,S$_o$	Effluent BOD$_5$,S	BOD$_5$ removal	Flow, Q	MLVSS, X
No.	Volume, l	mg/l	mg/l	%	l/day	mg/l
1	10.9238	390	20	95	6.4984	300
2	12.4320	390	9	98	3.2638	230
3	11.2908	390	39	90	15.6166	310
4	11.3684	390	22	94	8.2957	240
Calculated Data						
Reactor		Detention time, θ	1/S	$\dfrac{\theta.X}{S_o-S}$	$\dfrac{S_o-S}{\theta.X}$	1/θ
No.	Volume, l	day				
1	10.9238	1.681	0.05	1.36	0.74	0.595
2	12.4320	3.809	0.111	2.30	0.44	0.263
3	11.2908	0.723	0.026	0.64	1.56	1.383
4	11.3684	1.3704	0.046	0.89	1.12	0.730

Y and K$_d$ Determination

Equation (1) was adopted in determining Y and K$_d$ (George et al., 2004).

$$\frac{1}{\theta_c} = Y\frac{S_o - S}{X.\theta_c} - K_d \tag{1}$$

Since the reactors were operated without recycling, then the value of θ_c is taken equal to θ.

$\frac{1}{\theta_c}$ was plotted along the y-axis of Figure 2 and $\frac{S_o-S}{X.\theta_c}$ along the x-axis. The plotted data was fitted by the means of linear regression line. The slope of the line and the intercept with the y-axis were used to determine Y and K$_d$. The equation of the fitted line was found to be as:

y= 0.745x+0.06 with R^2 value of 0.9

K$_s$ and k Determination

Equation (2) was used in determining k and K$_s$ (George et al., 2004).

$$\frac{X\theta_c}{S_o - S} = \left[\frac{K_s}{k}.\frac{1}{S}\right] + \frac{1}{k} \tag{2}$$

Equation (2) was plotted with $\frac{X\theta_c}{S_o-S}$ along the y-axis and 1/S along the x-axis. The plotted data represented by Figure 3 was fitted by the means of linear regression line. The slope of the line and the intercept with the y-axis were used to determine k and K$_s$. The equation of the fitted line was found to be as:

y=12.337x+0.1761 with an R^2 equal to 0.95.
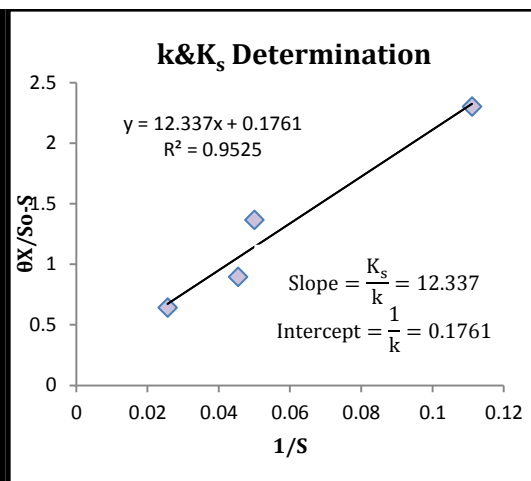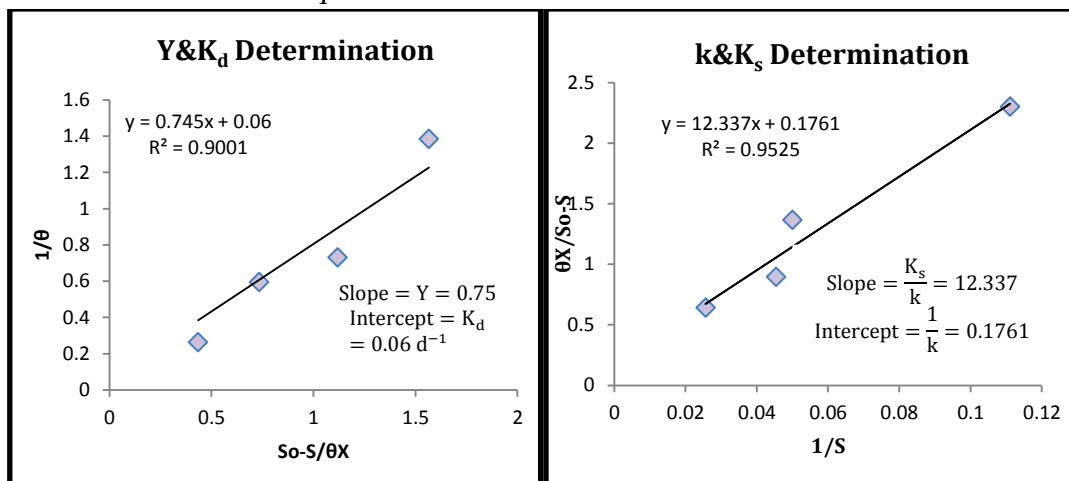
Figure 2. Y and K$_d$ Determination.   Figure3. k and K$_s$ Determination

The results of the obtained biological kinetics, from Figure 2 and 3, are presented in Table 4.

Table 4: The Biological Kinetics of Diyala River.

Biological Kinetic	Units	Value	Parameter Base
Y	unitless	0.75	BOD_5
K_d	day^{-1}	0.06	BOD_5
k	day^{-1}	5.68	BOD_5
K_s	mg/l	70	BOD_5

It would be interesting to compare the biological kinetic of Diyala River from table 4 with other biological kinetics from literature for different types of wastes shown in Table 5.

It was found that the obtained kinetic parameters in this study lies within the range of the typical biological kinetics for activated sludge process used to remove organic matter from domestic wastewater shown in Table 5. The nearest second and third values from Table 5 was the biological kinetics of Swine waste treatment and Tannery treatment respectively, while all other treatment gave bio-kinetic values far from the obtained values in this study in one way or another. This is to be expected, since the swine and tannery wastes, like the domestic wastes, have high rates of organic matter, while some of the other waste types mentioned at Table 5 are rather industrial. Although the dairy and winery wastes are considered biodegradable wastes, but some of their bio-kinetics, especially the Y and k parameters, are far from Diyala river's kinetics. This may be due to the difference in the waste's compounds.

Table 5: Biological kinetics for different types wastes.

Wastewater Type	k, d^{-1}	K_s, mg/l	Y, mg/mg	K_d, d^{-1}	Coe. Basis	Reference
Domestic	-	25-100~ 60	0.4-0.8~0.6	0.06-0.15~0.1	BOD	George et al., 2004
	2-10 ~ 5	10-60 ~ 40	0.3-0.6~0.4	-	COD	
Pulp and Paper mill	5.0	500	0.47	0.19	BOD	Rashid, 1995
Tannery	3.125	488	0.64	0.035	BOD	Haydar and Aziz,2009
Textile	3.83	1303.56	0.70	0.01	BOD	Mumtaz et al., 2012
	5.20	3407.64	0.25	0.006	COD	
Automobile	0.75	110	1.1	0.28	COD	Moayed and Mirbagheri, 2010
Swine	1.8	167	0.51	0.108	COD	Pan and Drapcho, 2001
Dairy and Baby milk	0.12	158.76	0.171	0.0421	BOD	Sharif, 1999
Winery	0.28	175	0.26	0.12	COD	Montalvo, 2010

k is employed to find the biological reactor's volume. Smaller the k value, greater the required size of the reactor. The k value obtained of the river water ($5.68d^{-1}$) lies within the range of k given in table 5 for domestic waste, which indicates normal wastewater degradation.

Y predicts the amount of total sludge produced during treatment. The obtained value of Y (0.75), performed on the bases of BOD_5, is slightly higher than the typical value given in table 5 for domestic waste, but it lies within its given general range.

K_d estimates the size and cost of sludge handling facilities by estimating the net sludge that needs to be handled. The obtained value of K_d (0.06) lies in the lower limit of the given range in table 5 for domestic waste, which indicates a great amount of wasted sludge that should be dealt with.

K_s give an indirect indication of the biomass specific growth changes. The obtained value of K_s (70 mg/l), performed on the bases of BOD_5, lies within the given range in table 5 for domestic waste, but it is slightly greater than its given typical value.

It is quite reasonable to expect to obtain biological kinetics for Diyala River near Al-Rustimiyah WWTP within the typical values of the domestic wastewater .That is duo to the untreated bypass flowing directly into the river from the WWTP's.

5. Conclusion

The biological kinetics k, Y, K_d, and K_s for the last part of Diyala River at AL-Rustimiyah WWTP's were found to be 5.68 d^{-1}, 0.75, 0.06 d^{-1}, and 70 mg/l, respectively. These values were classified within the ranges of the bio-kinetic parameter's typical values for activated sludge process treating domestic wastewater.

These results indicate that the water in Diyala River at its last part is rather wastewater than pure river water, and it needs to be treated urgently in order to restore its original clean environment.

Acknowledgment

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