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Kinetic Coefficients for the Biological Treatment of Tannery Wastewater Using Activated Sludge Process

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ABSTRACT

Activated sludge process is a highly effective and commonly adapted method of aerobic biological treatment systems and is normally designed on the basis of simplified hydraulic related parameters. Designs of biological treatment systems based on hydraulic considerations are not adequate to ensure efficient operation. This is due to the wide variation in the composition of wastewater and the complex nature of the biochemical reactions occurring in the treatment processes. Hence design of biological treatment systems should be based on the kinetic approach rather than hydraulic parameters considerations. The present study was aimed at developing kinetic coefficients for the treatment of tannery wastewater by activated sludge process. A laboratory scale completely mixed continuous flow reactor was used for the study. The reactor was operated continuously for 86 days by varying detention times from 3 to 9 days. Influent for the reactor was settled tannery wastewater. BOD of the influent and effluent and MLSS of aeration tank were determined at various detention times to generate data for kinetic coefficients. The kinetic coefficients k (maximum substrate utilization rate), K_s (half velocity constant), Y(cell yield coefficient) and K_d (decay coefficient) were found to be 3.125 day^{-1}, 488 mg/L, 0.64 and 0.035 day^{-1}, respectively. These coefficients may be utilized for the design of activated sludge process facilities for tannery wastewater. Overall BOD removal rate constant 'K' was found to be 1.46 day^{-1}.

Key Words: Kinetic coefficients; tannery wastewater; activated sludge process; aerobic treatment; industrial wastewaters.

1. Introduction

Leather industry is the second highest foreign exchange earning industry of Pakistan after the textile sector [1]. There are over 650 tanneries in Pakistan with major clusters located in Kasur, Karachi, Sialkot, Multan, Gujranwala and Sheikhupura districts [2]. The major pollution parameters for tannery wastewater are biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, nitrogen, sulfides, sulfates and chromium. Most of the times tanning industries in Pakistan discharge their untreated effluent in the receiving water bodies adversely affecting the aquatic life and human health.

After full-scale implementation of ISO 14001 in the year 2005, the foreign buyers are now much concerned about the adoption of environmental friendly practices during leather production. Due to this concern, tanning industries in Pakistan are under tremendous pressure to carry out treatment of their wastewaters to compete in the global market. Thus a rapid introduction of treatment facilities in tanneries, especially those which are export oriented, is envisaged. This trend is already

in evidence. Construction of primary treatment facilities has been either completed or is under process in many tanneries [3]. Some of these tanneries are now heading towards the secondary treatment of their wastewater in order to comply with the National Environmental Quality Standards (NEQS) [4].

Biological methods, like activated sludge process, are invariably employed for the secondary treatment of a large number of industrial wastewaters. Knowledge of the microbial kinetics and determination of the kinetic coefficients for a particular wastewater are, therefore, imperative for the rational design of treatment facilities [5]. No local reference is available in the literature for the kinetic coefficients of tannery wastewater. Designers, while designing biological treatment facilities (like activated sludge process) for tannery wastewater use hydraulic approach which does not result in an efficient treatment system meeting NEQS. In view of the above, the present study was undertaken with the objective to determine different kinetic coefficients for tannery wastewater so that these may be utilized for the design of treatment facilities in tannery sector.

2. Materials and Method

Laboratory scale reactors are normally used to determine kinetic coefficients. Completely mixed continuous flow reactor without recycle is usually employed for its easy operational control. In such a reactor, detention time (θ) is equals to mean cell residence time (θ_c). The procedure is to operate the unit over a range of effluent substrate concentrat-ions. Hence, several different θ_c (at least five) are selected for operation ranging from 1 to 10 days. Using the data collected at steady state conditions, mean values are determined for influent BOD (S_o), effluent BOD (S), and mixed liquor suspended solids (MLSS) of the aeration tank (denoted by X) to find out the kinetic coefficients [6].

The laboratory scale reactor used in this study has been shown in Fig. 1. The reactor was made of perspex glass of 5 mm thickness. The wastewater to the reactor was fed using a 20-litre glass bottle. Peristaltic pump was used to regulate flow for a particular θ_c. The capacity of the aeration tank was 36 liters. Diffuser stones were used to supply air and were placed at the bottom of the aeration tank along the wall. Filtered air was supplied to the diffusers stones from an air pump. A final clarifier followed the aeration tank with 4.2 liters capacity.

Wastewater samples for laboratory scale reactor were collected from a local tannery named Saddiq Leather Works. The tannery was equipped with a primary treatment plant comprising of equalization tank, primary sedimentation tank (PST), decanter and sludge drying beds (Fig. 2). The detention times in equalization tank and PST at maximum wastewater flow of 1700 m3/day were 6.4 hours and 3.9 hours, respectively.

In tanneries, all the processes are carried out as batch operations and wastes originating thereof vary considerably in composition. Hence the wastewater samples were collected at the outlet point of PST to get reasonably homogenous samples (Fig.2).

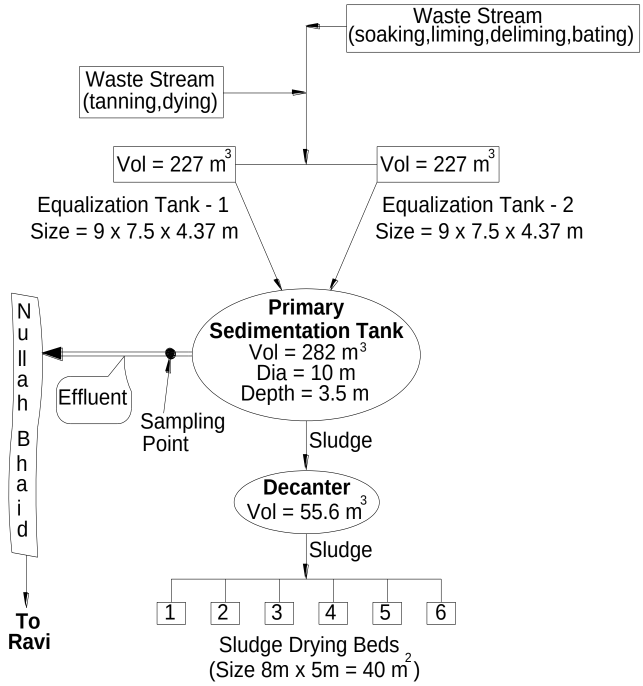

Fig. 2: Line sketch of primary treatment plant at Saddiq Leather Works

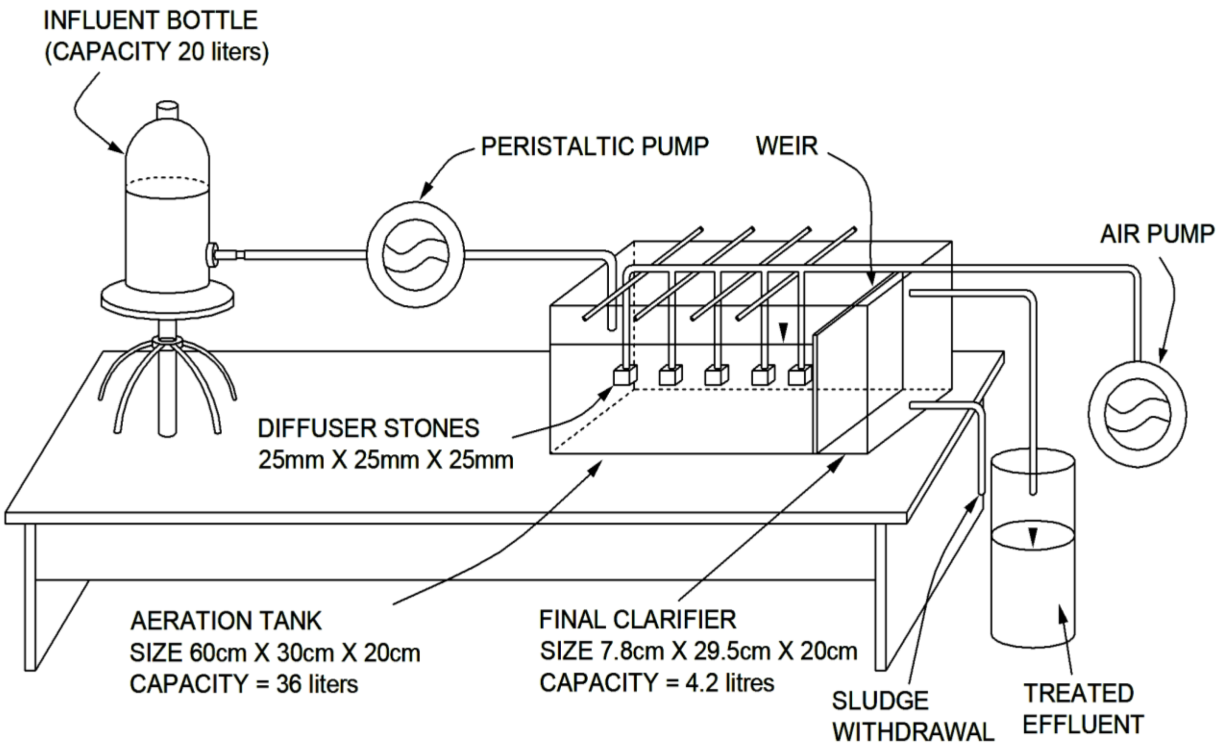

Fig. 1: Line sketch of laboratory scale completely mixed continuous flow reactor.

Total Kjeldahl Nitrogen (TKN) and Phosphorous (P) tests were carried out on the settled wastewater collected to check the level of these nutrients for satisfactory biological treatment. The BOD : N : P for the wastewater was found to be 100:21:0.19 as against a recommended value of 100:5:1 [7]. The phosphorous was thus deficient and this deficiency could hamper a satisfactory biological treatment. Therefore, the deficiency was met by adding calculated amount of Potassium Dihydrogen Phosphate (KH_2PO_4) in the wastewater.

Bench scale reactor was started on 7.06.2003. After seeding with domestic sewage, it was run as a batch system up to 09.06.2003 to develop biomass. Thereafter, it was run on a continuous basis till 6.09.2003. Complete operational schedule of the reactor is given in Table 1.

Table 1: Operational schedule of laboratory scale reactor

Date: From	Date: To	No. of Days	Flow Rate (L/day)	θc (Days)
9.06.2003	4.07.2003	26	12	3
5.07.2003	18.07.2003	14	9	4
19.07.2003	1.08.2003	14	7.2	5
2.08.2003	15.08.2003	14	5.14	7
16.08.2003	6.09.2003	18	4	9
	Total	86		

Samples from the influent to the reactor and effluent from the final clarifier were simultaneously collected to carry out BOD tests. Samples from the reactor were collected to find out MLSS, dissolved oxygen (DO), pH and temperature. Mean values of S_o, S and X at various θ_c were used to find out kinetic coefficients while DO, pH and temperature tests were carried out to ensure favorable environmental conditions in the reactor for biological treatment. All the tests were carried out as per procedures laid down in the "Standard Methods" [8].

3. Results and Discussion

Kinetic coefficients of interest for the design of activated sludge process are:

k = Maximum rate of substrate utilization per unit mass of microorganisms, time^{-1}

K_d = Endogenous decay coefficient, time^{-1}

K_s = Half velocity constant, substrate concentration at one-half of the maximum growth rate, mass/unit volume

Y = Cell yield coefficient, mg/mg (defined as the ratio of the mass of cells formed to the mass of substrate consumed.

'k' value is employed to find out the volume of biological reactors. Greater is the value of k, smaller will be the size of reactor [9]. K_s has no direct application in process design. It only gives an idea about the change in the specific growth rate of bacteria with a change in the concentration of the growth limiting substrate. Y is used to estimate the total amount of sludge produced as a result of wastewater treatment. K_d is used to find out the net amount of sludge to be handled and hence the size and cost of the sludge handling facilities can be found out from this information [9].

Data to determine above coefficients were generated by operating the bench scale reactor at different θ_c. Mean values of S_o, S and X corresponding to each θ_c are presented in Table 2.

The following linearized equation was used to find k and K_s [6].

$$\frac{X\theta_c}{S_o - S} = \frac{K_s}{k}\frac{1}{S} + \frac{1}{k} \qquad (1)$$

By using the above equation, a graph was plotted with 1/S on the x-axis and $X\theta_c/(S_o\text{-}S)$ along y-axis (Fig. 3). A linear regression line was fitted to the plotted data. Intercept on the y-axis and the slope of this line were used to find k and K_s. The equation of the fitted line is also shown on the graph.

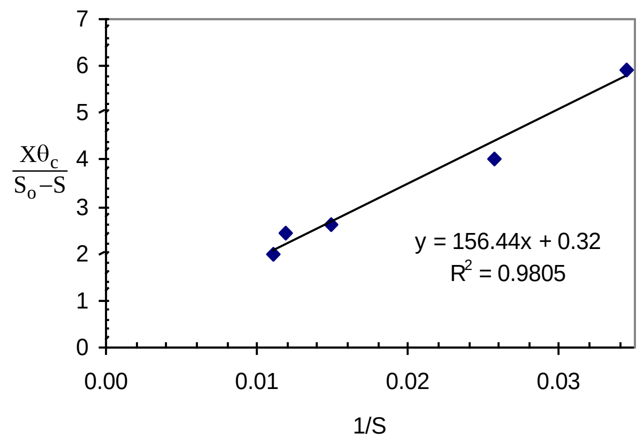

Fig. 3: Determination of k and K_s

Table 2: Mean values of data for kinetic coefficients

θ_c (days)	n[1]	S_o (mg/L) Range	S_o (mg/L) Mean[2]	S (mg/L) Range	S (mg/L) Mean[2]	X (mg MLSS/L) Range	X (mg MLSS/L) Mean[2]
3	6	451-620	535 ± 64	69-135	90 ± 24	250-330	297 ± 30
4	6	435-593	514 ± 54	65-110	84 ± 16	237-278	260 ± 18
5	6	416-529	480 ± 43	53-81	67 ± 10	171-261	217 ± 34
7	6	442-610	525 ± 73	29-53	39 ± 10	252-320	279 ± 26
9	6	433-544	497 ± 44	20-39	29 ± 8	268-339	308 ± 24

[1]Number of samples
[2]Mean ± Standard Deviation

The following linearized equation was used to find Y and K_d.[6].

$$\frac{1}{\theta_c} = Y\frac{S_o - S}{X\theta_c} - K_d \qquad (2)$$

A graph was plotted with $1/\theta_c$ along y-axis and $(S_o\text{-}S)/X\theta_c$ along x-axis (Fig. 4). A linear regression line was fitted to the plotted data. Intercept on y-axis and the slope of the line was used to find K_d and Y. The equation of the fitted line is also shown on the graph.

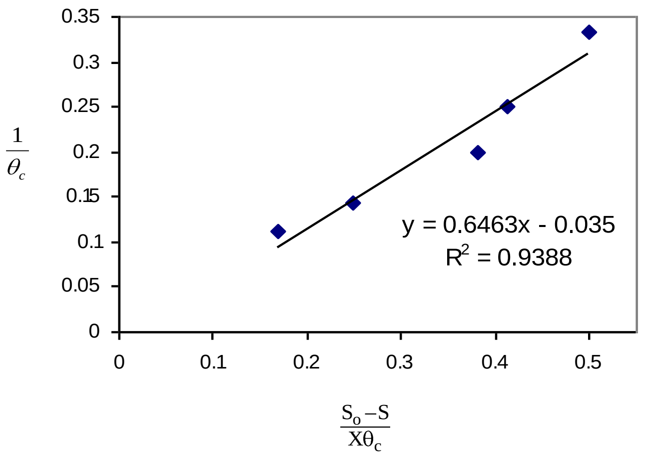

Fig. 4: Determination of K_d and Y

The values obtained for k, K_s, Y and K_d (from Fig. 3 and Fig. 4) are presented in Table 3.

Table 3: Kinetic coefficients for tannery wastewater.

Kinetic coefficient[1]	Value	Units
k	3.125	day^{-1}
K_s	488	mg/L
Y	0.64	unitless
K_d	0.035	day^{-1}

[1]At a mean reactor temperature of 30.2 ºC

No reference for the kinetic coefficients of tannery wastewater could be found in the literature for the purpose of comparison with other similar works. However, the results obtained were within the range noted for the kinetic coefficients of other industrial wastewaters as shown in Table 4.

A comparison of kinetic coefficients for tannery wastewater with other industrial wastewaters would be interesting. Substrate utilization rate 'k' for tanneries (3.125 day^{-1}) is less as compared to others and thus larger volume of biological reactor would be needed to treat tannery wastewater. This less value of 'k' may be due to specific nature of tannery waste. Decay coefficient Kd is quite low for tannery wastewater when compared with other industrial wastewaters, which indicates larger net sludge volumes resulting from biological treatment. Cell yield coefficient (Y) is comparable with other industrial wastewaters. Half velocity coefficient (Ks) is also comparable with the reported values except that for shrimp processing.

Table 4: Kinetic coefficients for some industrial wastewaters

Waste-water Type	Coeffi-cients	Unit	Typical Value	Coeffi-cients Basis
Pulp and Paper mill [10]	k	day^{-1}	5.0	BOD
	K_s	mg/L	500	
	Y	mg/mg	0.47	
	K_d	day^{-1}	0.19	
Pulp and Paper mill [11]	k	day^{-1}	6.4	BOD
	K_s	mg/L	539	
	Y	mg/mg	0.4	
	K_d	day^{-1}	0.16	
Shrimp Processing [12]	k	day^{-1}	36.9	BOD
	K_s	mg/L	85.5	
	Y	mg/mg	0.5	
	K_d	day^{-1}	1.6	

Overall BOD removal rate constant 'K' was also determined from the available data. 'K' can be employed for the design of other aerobic biological treatment systems such as aerated lagoon or waste stabilization ponds for the treatment of tannery wastewater [13]. For this purpose a graph was plotted with 'S' along x-axis and (So-S)/θc along y-axis (Fig. 5). A linear regression line passing through the origin was fitted to the plotted data [13]. The equation of the line is also shown on the graph. Slope of this line gave the value of 'K' as 1.46 day^{-1}. The result was in agreement with the findings of Metcalf and Eddy (2003), who reported that value of K varied from 0.5 to 1.5 day^{-1}.

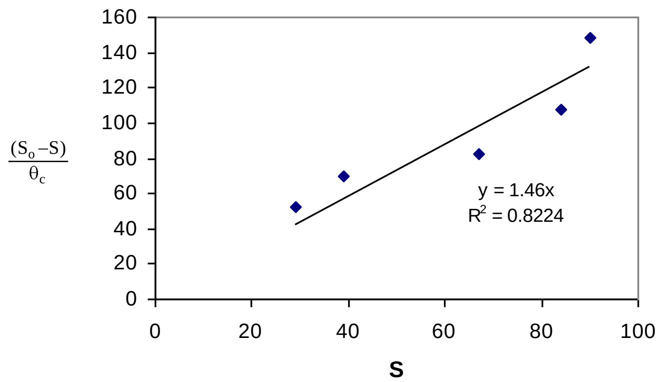

Fig. 5: Determination of 'K'

During the course of study, the reactor temperature fluctuated between 29 to 31°C, which falls within the suitable temperature range for heterotrophs treating wastewater under aerobic conditions [14]. The pH of the reactor remained between 6.5 and 8.0 which is a suitable range for biological treatment [9,15].

DO of the reactor remained between 3 and 4.5 mg/L which was above the desirable range of 2 mg/L for biological treatment [9,16].

4. Conclusions

The kinetic coefficients k (maximum substrate utilization rate), Ks (half velocity constant), Y (cell yield coefficient) and Kd (decay coefficient) were found to be 3.125 day^{-1}, 488 mg/L, 0.64 and 0.035 day^{-1}, respectively. The determination of these coefficients may be helpful in (1) understanding the kinetics of substrate utilization (2) sludge production and (3) design of biological treatment facilities based on activated sludge process for settled tannery wastewater. Thus these coefficients have both academic value and practical significance. The value of overall BOD removal rate constant 'K' was found to be 1.46 day^{-1} and this value may be employed for the design of aerobic biological treatment facilities based on aerated lagoon or waste stabilization ponds.

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