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Assessment of Kinetic Coefficients for Chrome Tannery Wastewater Treatment by Activated Sludge System

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ABSTRACT

Activated sludge process is feasible and extensively method used for biological treatment of sewage and industrial wastewaters. The system is usually designed based on the simplified hydraulic related parameters. But design of biological treatment system based on hydraulic considerations is not reasonable to ensure efficient treatment due to the extensive variation in the composition of wastewater and also for complex nature of biochemical reactions occurring in the treatment processes. Hence kinetic approach can be an option for appropriate design of biological treatment systems rather than hydraulic parameters considerations. The present study is aimed to develop kinetic coefficients for the treatment of chrome-tannery wastewater using activated sludge process. A laboratory-scale treatment unit subsuming an aeration tank and a clarifier were used for this system. The treatment unit was operated continuously for 80 days by varying the hydraulic retention time from 3 to 12 days. BOD for both influent and effluent as well as mixed liquor volatile suspended solid (MLVSS) of aeration tank were determined at different retention time to yield data for kinetic coefficients. The substrate utilization rate coefficient (k) was 0.624 day^{-1} while the half velocity constant (K_S) was 38.42 mg/L, yield coefficient (Y) was found to be 0.674 mgMLVSS/mgBOD and the endogenous decay coefficient (K_d) was found as 0.068 day^{-1}. These coefficients can be utilized for the rational design of activated sludge system for the treatment of chrome tannery wastewater.

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INTRODUCTION

Leather industry is considered as an enormous growth and investment potential sector in Bangladesh, earning $1.29 billion from exports in the 2013-14 fiscal and accounts for 4.2 percent of the country's total exports; yet the environmental burden associated with it has been a cause for great concern [1]. Annually about 85000 tons of raw material are processed from which about 20000 m^3 of highly polluted tannery wastewater is daily generated [2]. This tannery wastewater is characterized having high content of BOD, COD, suspended solids, sulphide, chloride and chromium etc. This untreated tannery effluents discharged directly into the water bodies or into the open lands and cause irreversible damage to the environment [3]. Because of the complex nature of tannery effluents, different types of physio-chemical process was studied for the applicability to the chrome-tannery wastewater treatment. These processes are coagulation, flocculation, adsorption, ozonation, reverse osmosis, and ion exchange [4]. The process of separation and treatment of wastewater individually demands excessive high cost, which is very difficult to afford for small or medium scale tanneries [5]. On this contrary, activated sludge system is a low cost and extensively used biological method for the treatment of tannery wastewater. For that reason, some of the tanneries have been moving to biological treatment system in combination with chemical treatment to satisfy the water quality according to Bangladesh environmental conservation rule 1997. Wastewater treatment by activated sludge method is well accomplished in different region of the world. It is conspicuous from the former research that the treatment of wastewater through aerobic biological system varies widely based on the nature of wastewater and heterogeneous bacterial population [6]. The design of biological treatment process for tannery wastewater treatment based upon the hydraulic consideration is not effective due to wide range of

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variation in the characteristics of the wastewater and the complex nature of the biochemical reactions resulting in the treatment system. Thus, the design and operation of biological treatment system demands a realistic model conjoining both biomass yield rate and substrate removal. Hence, design of biological treatment process considering kinetic approach can be a viable option rather than hydraulic consideration. Previously, a few investigation were carried out on the laboratory – scale activated sludge process for treating chrome-tannery wastewater in order to determine the different kinetics coefficients. [5-7]. But the kinetic coefficient found in these studies is not feasible for the context of Bangladesh due to different nature of tannery wastewater. Chromium containing tannery wastewater of Bangladesh is characterized with high BOD and COD load compared to that reported data by Hayder and Aziz [7] and Goswami and Mozumder [6] who carried out similar experiments in case of Pakistan and India, respectively. Analysis of kinetic coefficient and microbial kinetics are, therefore, essential for the effective rational design of tannery wastewater treatment facilities, particularly for Bangladesh. Hence, the present research was undertaken to develop the kinetic coefficients for the treatment of chrome-tannery wastewater of Bangladesh by activated sludge process.

MATERIAL AND METHODS

Sample collection and characterization

In order to characterize the tannery wastewater, composite (mix wastewater) samples were collected for several times from a local tannery named SAF Leather Industry, Jessore. Seed of aerobic biological treatment system was collected from ETP of Al-Muslim dyeing factory, Savar, Dhaka. Moreover, sewage water was also collected from local drain for seedling of microorganism. The collected samples were analyzed for various characteristic parameters like: pH, Total dissolved solids (TDS), Conductivity, Dissolved Oxygen (DO), Chemical oxygen demand (COD), Biological oxygen demand (BOD).

Mixed continuous flow reactor

In this study, kinetic coefficient of chrome tannery wastewater was determined using a laboratory scale reactor. A completely mixed continuous flow reactor without recycle was used in this study (Figure 1). The laboratory scale model was comprised of a reservoir tank, an aeration tank and a clarifier tank. The capacity of aeration tank was 22 liters. A clarifier tank with the capacity of 8 liters was setup following the aeration tank. Flow rate was controlled using valve. Laboratory scale compressor in conjunction with diffuser stones, installed at the bottom of the aeration tank, was used to supply air for maintaining the dissolve oxygen (DO) level in between 3 to 4.2 mg/l of the aeration tank for most of the time. This value is ideal for the biological treatment process under aerobic conditions [8]. The rate of microbial growth as well as total amount of growth can be affected by temperature and pH of the reactor. The temperature of the reactor was fluctuated from 24 to 35°C, whereas the pH of the reactor was maintained between 6.5 and 7.5 during the study period. Initially, seed of activated sludge, collected from an operational aerobic biological treatment system, and sewage water were taken in aeration tank where tannery wastewater was added daily in small quantity and aerated for microbial acclimation to tannery effluent. This acclimation process was carried out for 20 days. In such reactor, detention time (θ) is equals to mean cell residence time (θ_c). Treatment process was carried out for 80 days at six different detention time (θ) ranging from 3 to 12 days. At steady state conditions , the data was adopted and used to determine the mean value for influent BOD (So), effluent BOD (S) and mixed liquor volatile suspended solids (MLVSS) of the aeration tank (indicated by X) to calculate the kinetic coefficients. Before collecting the experimental data sufficient time was given to obtain the steady state condition. The content of mixed liquor volatile suspended solids (MLVSS) in the aeration tank was used to assess the steady state conditions. The pH, MLVSS and dissolved oxygen (DO) were the operating parameters for the bench scale aerated lagoon and measured continuously throughout the study period. Nitrogen and Phosphorus are indispensable nutrients for the growth and multiplication of microorganism. The recommended ratio of BOD : N : P is 100 : 5 : 1 [9]. Hence, deficient amount of nitrogen and phosphorus was met by adding urea (CH_4N_2O) and Potassium Dihydrogen Phosphate (KH_2PO_4), respectively.

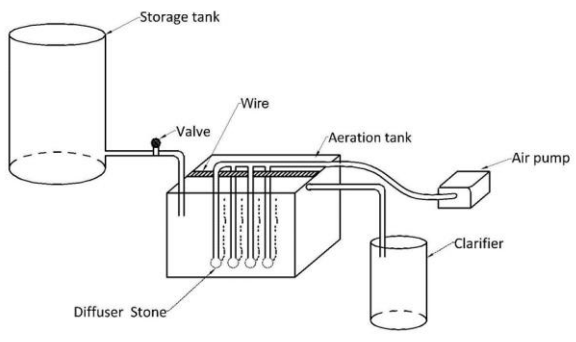

Figure 1: Laboratory bench scale activated sludge reactor

RESULTS AND DISCUSSION

During this study, the reactor was monitored daily on the basis of four parameters such as; pH, temperature, DO, and MLVSS. The first three parameters are related to biological growth of microorganism and have effect on the efficiency of biological treatment system but the latter parameter MLVSS was used to determine the kinetic coefficients. The treatment efficiency of the reactor on the basis of BOD_5 removal was conducted at different retention time.

TABLE1. Calculation of θ_C, S_o, S and MLVSS

Retention Time, days θ_C(Days)	Initial BOD_5, So, mg/L (mg/L)	Final BOD_5, S (mg/L)	X mg/L MLVSS
3	1582±394	110 ±21	821±60
4		70±10	848±45
5		52±10	784±68
7		30±7	688±42
9		15±5	651±37
12		15±6	569±52

Values are mean ± standard deviation

Food to microorganism ratio (F:M)

The F:M ratio is representative of the amount of food present on the tank to the number of microorganisms. An increase in this ratio means that the number of microorganisms presents in the tank have been reduced therefore, decreasing the removal efficiency of the reactor. Food to microorganism ratio (F:M) for BOD in kg BOD_5 (kg MLVSS)$^{-1}$ day^{-1} at different retention times with corresponding percentage of BOD_5 removal efficiencies are shown in Figure 2. The data indicated that F:M ratio and the efficiency of BOD_5 removal were inversely proportional to each other. Hence, an increase in F:M ratio resulting in reduction of removal efficiency. The range of F:M for BOD_5 was 0.1 to 0.90 kg BOD_5 (kg MLSS)$^{-1}$ day^{-1} corresponding to an efficiency of 98 to 95%. Figure 2 also reveals that BOD_5 removal increases with the increase of retention time up to 9 days and thereafter no changes in effluent quality. These values can facilitate the designers in the selection of an appropriate organic loading while aiming particular removal efficiency.

Evaluation of kinetic coefficients

For the determination of Kinetic coefficients, bench scale studies were conducted for different hydraulic retention times, i.e., 3, 4, 5, 7, 9, and 12 days. For each retention time, the data were collected at steady state conditions and mean values were determined for So (initial substrate concentration expressed as BOD_5, mg/L), S (final substrate Concentration as BOD_5, mg/L) and X (biomass concentration as MLVSS, mg/L). The average of three readings of each So, S and X were taken for each

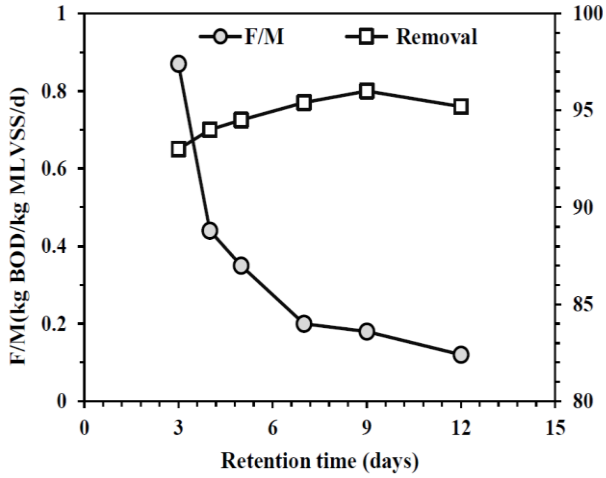

Figure 2: F/M ratio and removal of BOD

detention time shown in Table 1. Kinetic coefficients have potential importance for efficient design of the reactor. Two basic equations are used to explain mathematically the fundamental kinetics of the wastewater treatment. The following linearized equation was used to determine kinetic coefficients such as half saturation constant (K_S, mg/L), maximum specific substrate utilization coefficient (k, day^{-1}), yield coefficient (Y, mg/mg) and endogenous decay constant (k_d, day^{-1}). The following linearized Eq. (1) was used to determine k and K_S. Similarly, linearized Eq.(2) was used to determine Y and K_d [9]:

$$\frac{X\theta_c}{S_0 - S} = \frac{K_S}{K}\frac{1}{S} + \frac{1}{k} \quad (1)$$

$$\frac{1}{\theta_c} = Y\frac{S_0 - S}{X\theta_c} - K_d \quad (2)$$

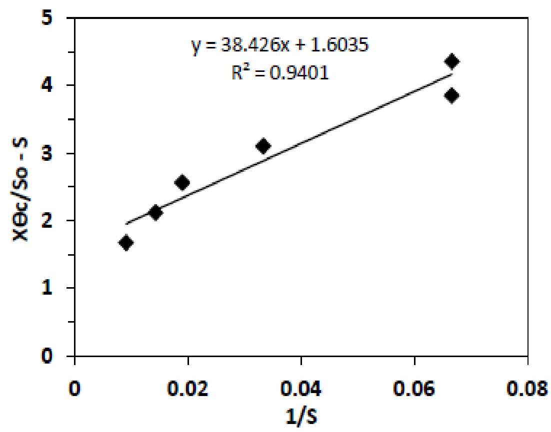

Figure 3: Determination of k and K_S

A graph was plotted with 1/S along X-axis and $X\theta_c/(S_o$-S) along Y-axis . A best fitted line was drawn through the plotted data which is shown in Figure 3. K_S and k were calculated from the slope and intercept respectively. k indicates the maximum rate of substrate utilization per unit mass of microorganisms. The value of k have impact on the volume of the reactor. The larger value of k, the smaller will be the size of the reactor [8]. It is audited from Figure 3 that the value of k is 0.624 day^{-1} which is very less as compared to the result found in the previous study by Hayder and Aziz [7]. But this result is in congruence with the result for composite chrome tannery wastewater by Goswami and Mazumder [6] shown in Table 2. As a result, greater volume of biological reactor would be required for the treatment of chrome-tannery wastewater. The lesser value of k may be due to the higher content of inorganic substances compared to degradable organic substances. The determined value of k for domestic wastewater [9] and textile wastewater [10] was found as 5 day^{-1} and 3.83 day^{-1} in previous studies shown in Table 2, which revealed that the maximum substrate utilization rate by microorganism is slightly less in the case of chrome-tannery wastewater as compared to domestic and textile wastewaters. This deviation may be due to the different composition of the wastewater.

KS is the half velocity constant which define the substrate concentration. The value of K_S for this study was found to be 38.42 mg/L (Figure 3). Similar result of K_S for tannery wastewater was found in the previous study [5, 6] though there is a dissimilarity with Hayder and Aziz [7]. Although, it has no direct application for process design but gives an idea about change in specific growth rate of microorganism [8].

Then a graph was plotted with $(S_o\text{-}S)/X\theta_C$ along X-axis and 1/θC along Y-axis for the determination of K_d and Y expressed in Figure 4. A best fitted line was drawn to the origin of the plotted data from which, K_d and Y were determined from the intercept and slope accordingly.

Yield coefficient (Y) measures how biomass is evolved against substrate utilization. During the study, the value of Y was found to be 0.674 $mgVSS/mgBOD_5$. This result is in congruence with that found in the other studies for chrome-tannery wastewater [6]. The value of Y gives an estimation of the sludge resulted from the wastewater treatment. The greater value of Y indicates the production of greater amount of sludge which will increase the size of sludge handling [8].

Endogenous decay constant (K_d) is the microbial decay coefficient and represents the biomass lost to endogenous respiration per unit of biomass per unit time [8]. During this study, the value of K_d was found to be 0.068 day-1. The range of K_d for tannery wastewater was found 0.024 - 0.295 in previous studies [6]. K_d value has significance in process designing when evaluating

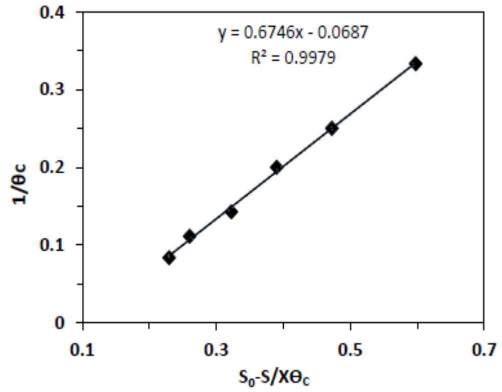

Figure 4: Determination of Y and K_d

net sludge production in a treatment facility. Higher values of K_d reduce the net production of sludge handling. The size and cost of the sludge handling facilities can be calculated with the value of Y and K_d.
Overall BOD removal rate constant (K) has great importance for the design of other aerobic biological treatment systems such as aerated lagoon or waste stabilization ponds for the tannery wastewater treatment [7]. In this study, K value was also determined. In this case, agraph was plotted where S and $(S_o\text{-}S)/\theta_c$ were placed in X-axis and Y-axis, respectively shown in Figure 5 [11]. A linear regression line was drawn through the plotted data. The value of K found from the slope of the line was 3.62 day-1.

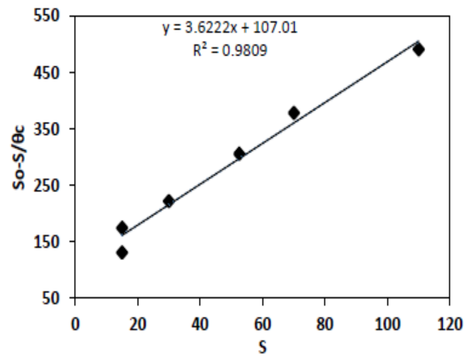

Figure 5: Overall BOD removal rate K

TABLE 2.

$K(day^{-1})$	Ks (mg/L)	Y (mg/mg)	$Kd(day^{-1})$	Wastewatertype
1.56-2.42	113-142	0.48-0.61	0.05-0.08	Tannery [5]
0.2	23.02	0.68	0.02	Tannery [6]
3.12	488	0.64	0.03	Tannery [7]
5	60	0.6	0.10	Domestic [9]
3.83	1320	0.70	0.01	Textile [10]
0.624	38.42	0.674	0.068	This study

CONCLUSION

The purpose of this study was to determine the efficiency of activated sludge system for the treatment of chrome tannery wastewater. On the basis of this study, the following major conclusions have been derived:

(1) The range of F:M on BOD basis was 0.1 to 0.90 kgBOD/kgVSS-d corresponding to an removal efficiency of 98 to 95%. BOD removal gradually rose with the increase of detention time up to 9 days.

(2) The values of kinetic coefficients k, K_s, Y and K_d on BOD basis were found to be 0.624 day^{-1}, 38.42 mg/L, 0.674 mgVSS/mgBOD and 0.068 day^{-1}, respectively.

(3) Overall BOD removal rate constant (K) for the tannery wastewater was evaluated to be 3.62 day^{-1} which can be used in the design of aerated lagoon or waste stabilization ponds for the treatment of tannery wastewater.

(4) Kinetic coefficients may be auspicious for understanding of some expression like: kinetics of substrate utilization, yielding of sludge and designing of wastewater treatment system based on activated sludge process for tannery wastewater.

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Persian Abstract

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چکیده

فرآیند لجن فعال روشی کارامد و گسترده برای تصفیه زیستی شیرابه و فاضلاب های صنعتی به‌شمار می‌آید. به طور معمول، طراحی این نوع از سیستم‌ها بر اساس پارامترهای ساده شده‌ی مبتنی بر هیدرولیک فرآیند انجام می‌پذیرد. اما این نوع از طراحی برای دستیابی به یک تصفیه کارامد و خوب منطقی به نظر نمی‌رسد؛ چرا که علاوه بر وجود متغیرهای گسترده در ترکیب فاضلاب، واکنش های بیوشیمیایی طی فرآیند تصفیه رخ خواهد داد که سینتیک و رفتاری پیچیده از خود نشان می‌دهند. بنابراین، دستیابی به سینتیک فرایندی می‌تواند گزینه مناسبی نسبت به بررسی متغیرهای هیدرولیکی در طراحی مطلوب سیستم های تصفیه بیولوژیکی باشد. پژوهش حاضر با هدف ارتقاء ضرائب سینتیکی فرایند تصفیه کروم- فاضلاب رنگرزی با استفاده از فرایند لجن فعال انجام گرفته است. طی آن، از یک واحد تصفیه‌ای در مقیاس آزمایشگاهی متشکل از یک مخزن هوادهی و یک زلال‌ساز استفاده گردید. فرآیند به طور پیوسته ظرف مدت ۸۰ روز و با تغییر زمان ماند هیدرولیکی از ۳ الی ۱۲ روز راه‌اندازی شد. اکسیژن موردنیاز بیولوژیکی (BOD) برای جریان ورودی و خروجی، همانند جامدات معلق فرار مخلوط (MLVSS) تانک هوادهی در زمان‌های ماند مختلف اندازه‌گیری گردید. مقادیر ضریب نرخ مصرف سوبسترا (k) برابر با ۰/۶۲۴ (day-1) و ثابت نیمه‌سرعت (KS) و ضریب بازدهی (Y) به ترتیب برابر با ۳۸/۴۲ میلی‌گرم بر لیتر و ۰/۶۷۴ (mgMLVSS/mgBOD) بدست آمد. علاوه بر این، ضریب تجزیه درونی (Kd) معادل ۰/۰۶۸ (day-1) محاسبه شد. ضرائب بدست آمده از این فرایند می‌تواند در طراحی منطقی یک سیستم لجن فعال در تصفیه کروم از فاضلاب رنگرزی لحاظ شود.