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Research Note

# Determination of Kinetic Parameters in Integrated Fixed Film Activated Sludge for Amol's Industrial Park Wastewater Treatment Plant

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In this study the performance of integrated fixed film activated sludge system (IFAS) in Amol industrial wastewater treatment plant (Amol, Iran) in treatment of food industrial wastewater was investigated. In addition, kinetic coefficients were evaluated for the system. The capacity of this system was 1700 cubic meters per day; that includes different process comprising physical and biological treatment, disinfection, sludge thickening, digestion and dewatering. COD removal efficiency and kinetic coefficients including yield coefficient (Y), half saturation coefficient (Ks), maximum substrate utilization rate constant (k) and endogenous decay coefficient (kd) were evaluated. The obtained results demonstrated that except Ks other coefficient were in the normal range that was frequently reported for conventional activated sludge in the literature. The COD removal efficiency was about 98 to 99 percent. The results indicated that there is a direct relationship between the variation of kd and Ks with effluent substrate concentration; while, the relationship between rate constant (k) and effluent COD is reversed. Finally, the effect of increasing sludge retention time (SRT) on COD removal was also studied. It was concluded that COD removal increased with an increase active solid retention time to a certain point, behind that point there was no significant changes observed.

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## INTRODUCTION

In past decades, attached growth system in combination with activated sludge process was successfully applied. The process received more attention over the traditional alternatives, as it needs relatively less Solid Retention Time (SRT) and less land area in compare to conventional activated sludge processes [1]. In fact, attached growth processes are more stable against hydraulic and organic load shocks than suspended growth modes [2].

Integrated fixed-film activated sludge (IFAS) combines the advantages of attached growth and suspended growth processes [3]. However, this process is not often economically suitable, since it requires high capital cost for the fixed media [2]. The IFAS process generally is applied in the municipal sector for enhancing nitrification or total nitrogen removal in existence of activated sludge facilities [4]. Several studies evaluated the performance of integrated fixed-film activated sludge for municipal and industrial wastewater treatment [5]. Paul *et al.* [6] have reported that a clear spatial distribution of microbial population between follicular biomass (heterotrophs) and fixed biomass (nitrifiers) leads to high chemical oxygen demand (COD) and N-removal performances.

Kinetic coefficient can be used in order to design an appropriate wastewater treatment process. Kinetic coefficient which are frequently used for conventional activated sludge system consist of maximum substrate utilization rate (k: 2-10 mg/L), half saturation coefficient ($K_s$: 10-60 mg/L), yield coefficient (Y: 0.3-0.6 mgVSS/mgCOD) and endogenous decay coefficient ($k_d$: 0.06-0.15 day$^{-1}$) [7]. Kinetic coefficient for several wastewater treatment systems has been evaluated [8-10]. In a research conducted by Al-Malack [11], kinetic coefficients were estimated for a wastewater treatment system in various loading rates. Naghizadeh *et al* [12] has determined kinetic parameters for Monod equation in

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submerged membrane reactor employed for the treatment of municipal wastewater. The obtained value for Y, $k_d$, $K_s$, k were 0.6 mgVVS/mgCOD, 0.51 $(day)^{-1}$, 65.5 mg/L and 1.86 $(day)^{-1}$, respectively [13]. In another research done for biological elimination of C:N:P, kinetic parameters were estimated. The kinetic coefficients were determined for a high-rate biological wastewater treatment plant in a fixed condition with hydraulic retention time (HRT) of 24 h [14, 15]. In laboratory scale and pilot scale bioreactor at different HRT and SRT for complete mixed reactor, kinetic parameters were determined [7]. In this work, food industrial wastewater obtained from wastewater treatment plant in Amol industrial park had wastewater treatment capacity of 1700 $m^3.day^{-1}$. This plant uses a two-stage aeration system, aerobic attached growth and extended aeration (polyethylene media is used as fixed bed with specific volume of 150 $m^2/(m^3$ wastewater)). Dairy industry contains about 70% of the total wastewater produced in this park and the rest 30% is attributed by other food and beverage industry.

In this study, kinetic parameters including Y, $k_d$, k and $K_s$ for IFAS was obtained. The obtained parameters were compared to conventional activated sludge system. Furthermore, COD removal efficiency was determined. In addition, sensitivity of kinetic coefficient focusing effluent COD was studied. Finally, the impact of SRT on COD removal was evaluated.

## MATERIAL AND METHODS

This research was performed in full scale in Amol industrial park wastewater treatment plant. Wastewater with flow rate of 1700 $m^3$ $(day)^{-1}$ was treated by IFAS. Data collection was continuously performed for duration of six months (started Winter 2013 till end of Spring 2014). Important parameters including COD, $BOD_5$, total suspended solid (TSS), mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS), sludge volume index and dissolved oxygen (DO) in aerobic attached growth reactor, extended aeration tank, equalizer tank and outlet stream of the wastewater treatment plant were determined. The described wastewater treatment plant has two modules which are paralleled and are similar in conditions and sizes. Hence, sampling was conducted only in one module and attributed to the whole plant. The flow diagram of this system is shown in Figure 1. Furthermore, specifications of principle unit and operating conditions of Amol industrial park wastewater treatment plant in the period of investigation is summarized in Table 1.

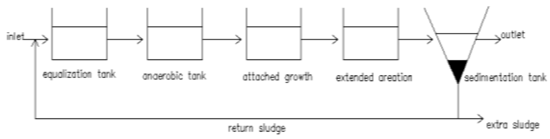



**Figure 1.** Flow diagram of Amol industrial park wastewater treatment plant

**TABLE 1.** Specifications of principle unit and operating conditions of Amol industrial park wastewater treatment plant in the period of investigation (Winter 2013 till Spring 2014)

| Unit | Number | Volume ($m^3$) | Operating conditions of Amol industrial park wastewater treatment plant | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Inlet | | | | | Extended aeration tank | | | | Outlet | | |
| | | | | **HRT (day)** | **Q ($m^3$/day)** | **COD (mg/L)** | **BOD (mg/L)** | **TSS (mg/L)** | **MLSS (mg/L)** | **MLVSS (mg/L)** | **SVI (mg/L)** | **DO (mg/L)** | **COD (mg/L)** | **BOD (mg/L)** | TSS (mg/L) |
| Equalizer tank | 1 | 660 | Range | 0.36-0.57 | 1150-1850 | 1790-5000 | 1100-3500 | 100-1200 | - | - | - | - | 1700-5000 | 980-3400 | 80-1200 |
| | | | Avg | 0.47 | 1416 | 3460 | 1930 | 545 | - | - | - | - | 3400 | 1890 | 523 |
| Anaerobic rector | 2 | 451 | Range | 0.49-0.78 | 575-925 | 1700-5000 | 980-3400 | 80-1200 | - | - | - | - | 980-2230 | 530-1170 | 210-600 |
| | | | Avg | 0.64 | 708 | 3400 | 1890 | 523 | - | - | - | - | 1539 | 780 | 363 |
| Aerobic attached growth reactor | 2 | 109 | Range | 0.12-0.2 | 575-925 | 980-2230 | 530-1170 | 210-600 | - | - | - | - | 232-1254 | 130-660 | 40-72 |
| | | | Avg | 0.15 | 708 | 1539 | 780 | 363 | - | - | - | - | 612 | 340 | 65 |
| Extended aeration tank | 2 | 641 | Range | 0.69-1.11 | 575-925 | 232-1254 | 130-660 | 40-72 | 1450-2030 | 900-1600 | 85-260 | 1.5-3.5 | - | - | 1320-2980 |
| | | | Avg | 0.9 | 708 | 612 | 340 | 65 | 2159 | 1240 | 163 | 2.55 | - | - | 2390 |
| Sedimentation tank | 6 | 89 | Range | 0.29-0.46 | 192-308 | - | - | 1400-3040 | - | - | - | - | 34-100 | 14-32 | 30-52 |
| | | | Avg | 0.42 | 211 | - | - | 2420 | - | - | - | - | 49 | 19 | 37 |

Kinetic coefficient of the IFAS system is determined utilizing the following equations for the collected data:

$$\frac{1}{SRT} = YU - k_d = \frac{Y(S_0 - S)}{\theta X} - k_d \quad (1)$$

$$\frac{\theta X}{S_0 - S} = \frac{K_s}{k}\frac{1}{S} + \frac{1}{k} = \frac{1}{U} \quad (2)$$

Where SRT refers to the sludge retention time ($day^{-1}$), $S_0$ is the inlet substrate concentration (mg COD/L), U is the substrate utilization rate (mg COD/mg VSS), $K_d$ represents the endogenous decay coefficient ($day^{-1}$), Y is the biomass yield coefficient (mgVVS/mgCOD), X is biomass concentration (mgVVS/L), θ refers to the hydraulic retention time (HRT) ($day^{-1}$), $K_s$ is half saturation coefficient (mg COD/L) and k is the maximum substrate utilization rate (mg COD/mg VVS. day).

Kinetic coefficient can be obtained by plotting 1/U vs 1/S and 1/SRT vs U. Y-intercept and slope of 1/SRT vs U represent endogenous decay coefficient ($k_d$) and biomass yield coefficient (Y), respectively. Similarly, Y-intercept and slope of 1/U vs 1/S represent 1/k and $K_s$/k, respectively.

Outlet substrate concentration and COD removal efficiency is calculated by following equations:

$$S=\left[\frac{K_s\left[\frac{1}{SRT}+k_d\right]}{k-\left[\frac{1}{SRT}+k_d\right]}\right] \quad (3)$$

$$R=\left(\frac{COD_{in}-COD_{out}}{COD_{in}}\right)*100 \quad (4)$$

where R refers to the COD removal efficiency.

In order to define the most effective parameter on COD removal efficiency, sensitivity of these parameters were investigated. For this purpose k, kd, Ks were altered for ±50%, whereas other parameters keep constant and for all experiments SRT were considered 25 (days). Subsequently, sensitivity of kinetic coefficient was determined by estimation of COD for outlet stream based on Eq. 3 and then variation of kinetic coefficient was plotted versus COD variations.

## RESULTS AND DISCUSSION

Collected data and calculated results obtained from inlet wastewater, aerobic attached growth reactor, extended aeration tank and outlet stream was categorized in two section according to the range of MLSS in extended aeration tank. In order to calculate the kinetic parameters, the collected data for MLSS in the range of 1450-2000 mg/L were plotted and equations 1 and 2 were fitted (see Figure 2). The Y and kd were obtained from the linearly fitted Eq. 1 using experimental data (as discussed previously). Similarly, 1/k and K0/k were obtained from the plot of 1/U vs 1/S.

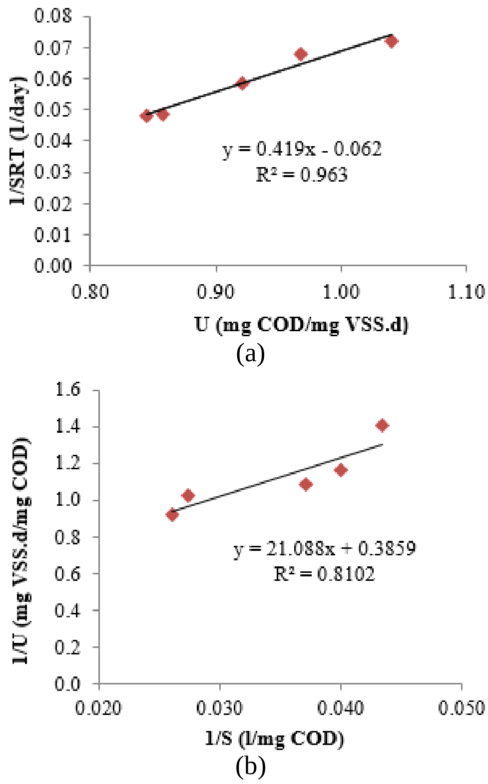


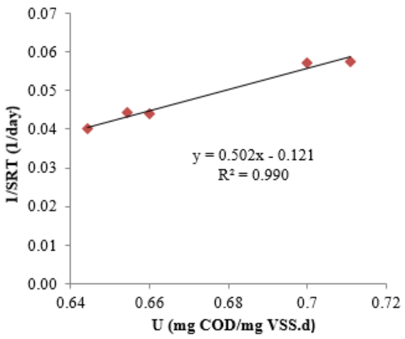

**Figure 2.** Determination of kinetic coefficient for MLSS=1450-2000 mg/L (a) Evaluation of $k_d$ and Y (b) Evaluation of k and $K_s$

According to presentation of data in Figure 2, kinetic parameters value in range of MLSS=1450-200 mg/L were 0.419 mg/mg, 0.062 $day^{-1}$, 2.6 $day^{-1}$ and 54.7 mgCOD/L for Y, $k_d$, k and $K_s$, respectively.

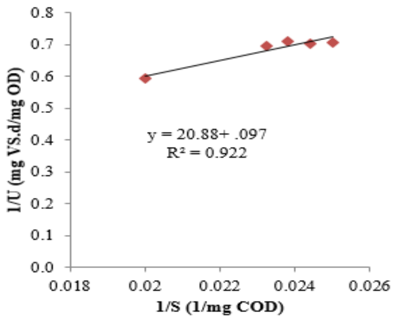
Experimental data for MLSS=2000-3500 mg/L are summarized in Table 2. Similarly, kinetic coefficients based on linear plots of 1/SRT vs U and 1/U vs 1/S were obtained (see Figure 3). For this case, kinetic parameters including Y, $k_d$, k and $K_s$ were determined to be 0.502 mg/mg, 0.121 $day^{-1}$, 10.3 $day^{-1}$ and 215.2 mgCOD/L, respectively.

As evidenced from the results which are summarized in Tables 2, COD removal efficiency in the described IFAS system were approximately 98-99%, indicating that this system has better performance in compare to conventional activated sludge system, even in high MLSS concentration. The kinetic parameters which were obtained and reported in different articles for various systems are summarized in Table 3.

The results presented in Table 4, indicated that all kinetic coefficient, except $K_s$, were in the normal range of conventional activated sludge system. The observed exception for $K_s$ is due to the fact that $K_s$ value is related to $k_d$, so that every uncertainty in estimation of $k_d$, influence on $K_s$ value. This problem is more comprehensive in high value of MLSS [11].




(a)




(b)

**Figure 3.** Determination of kinetic coefficient for MLSS=1450-2000 mg/L (a) Evaluation of kd and Y (b) Evaluation of k and Ks

**TABLE 2.** Performance parameters for wastewater treatment plant in Amol industrial park in MLSS=2000-3500

| Q ($m^3$/day) | HRT (day) | MLVSS (mg/L) | COD in (mg/L) | COD out (mg/L) | SRT (day) | F/M (1/day) | COD removal efficiency (%) |
|---|---|---|---|---|---|---|---|
| 576 | 1.13 | 1300 | 1950 | 45 | 22.6 | 0.65 | 98 |
| 533 | 1.20 | 1400 | 2200 | 55 | 25 | 0.64 | 98 |
| 467 | 1.37 | 1460 | 2870 | 42 | 17.4 | 0.71 | 99 |
| 578 | 1.11 | 1270 | 1850 | 44 | 23.2 | 0.66 | 98 |
| 458 | 1.39 | 1420 | 2690 | 52 | 18.6 | 0.70 | 99 |

**TABLE 3**. Comparison of reported kinetic coefficient in other literature by present study

| Kinetic coefficient | Units | Metcalf &Eddy [7] | Joseph *et al.* [15] | Pala and Bölükbaş [14] | Al-Malack [11] | Naghizadeh *et al.* [12] | This study |
|---|---|---|---|---|---|---|---|
| Y | mg/mg | 0.4-0.8 | 1.78 | 0.4-0.67 | 0.49-0.58 | 0.67 | 0.419-0.50 |
| kd | 1/day | 0.025-0.07 | 0.12 | 0.07-0.09 | 0.037-0.01 | 0.5 | 0.062-0.12 |
| K | 1/day | 2-10 | 0.28 | 3.2-3.75 | 1.28-6.46 | 1.86 | 2.6-10.3 |
| Ks | mg/L | 15-70 | 36.6 | 22-60 | 289-2933 | 65.5 | 54.7-215. |

Sensitivity analysis was performed to determine the parameters which influence on substrate concentration of effluent. For this purpose, the value of $K_s$, k and $k_d$ was separately altered (± 50%), whereas other parameters keep constant (retention time consider 25 days for all cases). Sensitivity of kinetic coefficient were studied by estimation of outlet COD by plotting the value of COD in outlet stream against variation of kinetic coefficient and subsequently fitting data in Eq. 3 to plot experimental data. Results are presented in Figures 4 and 5.

As shown in Figures 4 and 5, $k_d$ and $K_s$ are proportional to outlet COD concentration, but k has reverse proportion to outlet COD. It was concluded that concentration of outlet COD is more sensitive to k than $k_d$ and $K_s$.

In order to determine the effect of SRT on COD of outlet stream, COD removal efficiency was calculated via Eqs. 3 and 4 for two different ranges of MLSS (1450-2000 mg/L and 2000-3500 mg/L). Figure 6 clearly indicates that outlet COD decrease with increase in sludge retention time to a certain point, but after that it is not so effective.

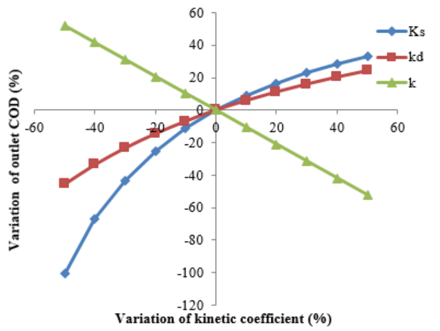



**Figure 4.** Sensitivity of kinetic coefficient for MLSS= 1450-2000 mg/L

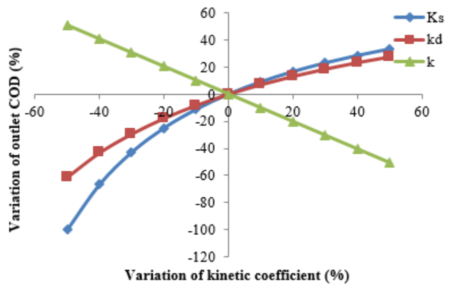



**Figure 5.** Sensitivity of kinetic coefficient for MLSS= 2000-3500 mg/L

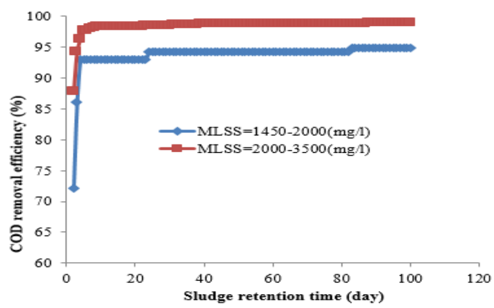



**Figure 6.** The effect of SRT on COD removal efficiency in two different ranges of MLSS

## CONCLUSION

Integrated Fixed Film Activated Sludge system has demonstrated to be a promising technology for treatment of various kind of wastewater, especially in industrial wastewater, because of its high efficiency, low operational cost and simple design. This system may be serving as a solution for wastewater treatment plants which need to be extended in size, without adding any additional tanks or changing tank size. This system was studied successfully in Amol industrial park wastewater treatment plant. It was concluded that COD removal efficiency was about 99% and this performance was obviously better than conventional activated sludge system. The results demonstrated that all kinetic coefficient, except $K_s$, were in the normal range of conventional activated sludge process. It was indicated that $k_d$ and $K_s$ are proportional to outlet COD concentration, but k has reverse proportion to outlet COD. Finally, it was concluded that concentration of outlet COD is more sensitive to k than $k_d$ and $K_s$.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## REFERENCES


1. Abdel_Kader, A.M. *COMPARISON STUDY BETWEEN INTEGRATED FIXED FILM ACTIVATED SLUDGE (IFAS), MEMBRANE BIOREACTOR (MBR) AND CONVENTIONAL ACTIVATED SLUDGE (AS) PROCESSES*. in *16th International Water Technology Conference, Istanbul, Turkey*. 2012. Citeseer.
2. Farrokhi, M., D. Ashrafi, E. Roohbakhsh and A. Yoonesi, 2014. Hospital Wastewater Treatment by Integrated Fixed Film Activated Sludge, Using Rice Husk as Fixed Media. Advances in Life Sciences, 4(3): 178-183.
3. Jou, C.-J.G. and G.-C. Huang, 2003. A pilot study for oil refinery wastewater treatment using a fixed-film bioreactor. Advances in Environmental Research, 7(2): 463-469.
4. Onnis-Hayden, A., D. Dair, C. Johnson, A. Schramm and A.Z. Gu, 2007. Kinetcis and nitrifying populations in nitrogen removal processes at a full-scale integrated fixed-film activated sludge (IFAS) plant. Proceedings of the Water Environment Federation, 2007(15): 3099-3119.
5. Rutt, K., J. Seda and C.H. Johnson, 2006. Two year case study of integrated fixed film activated sludge (IFAS) at Broomfield, CO WWTP. Proceedings of the water environment federation, 2006(13): 225-239.
6. Paul, E., D.B. Wolff, J.C. Ochoa and R.H. Ribeiro da Costa, 2007. Recycled and virgin plastic carriers in hybrid reactors for wastewater treatment. Water environment research, 79(7): 765-774.
7. Tchobanoglous, G., F.L. Burton and H. Stensel, Metcalf & Eddy,(2003).". Wastewater engineering: Treatment and reuse, 4.
8. Henze, M., 1992. Characterization of wastewater for modelling of activated sludge processes. Water Science and Technology, 25(6): 1-15.
9. Kovárová-Kovar, K. and T. Egli, 1998. Growth kinetics of suspended microbial cells: from single-substrate-controlled growth to mixed-substrate kinetics. Microbiology and molecular biology reviews, 62(3): 646-666.
10. San, H.A. and R.M. Sykes, 1994. Mechanism of Biological Treatment in Plug-Flow or Batch Systems. Journal of Environmental Engineering-American Society of Civil Engineers, 120(1): 267.
11. Al-Malack, M.H., 2006. Determination of biokinetic coefficients of an immersed membrane bioreactor. Journal of Membrane Science, 271(1): 47-58.
12. Mrudula, S. and R. Anitharaj, 2011. Pectinase production in solid state fermentation by Aspergillus niger using orange peel as substrate. Glob. J. Biotechnol. Biochem, 6(2): 64-71.
13. NAGHIZADEH, A., E. DERAKHSHANI and A.R. YARI, 2013. Study of Kinetic coefficients of a Membrane Bioreactor (MBR) for municipal wastewater treatment.
14. Pala, A. and Ö. Bölükbaş, 2005. Evaluation of kinetic parameters for biological CNP removal from a municipal wastewater through batch tests. Process Biochemistry, 40(2): 629-635.
15. Neill, G.J., High-rate biological treatment of wastewater at the Pantex facility1999.

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**Persian Abstract**

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**چکیده**

در این مطالعه عملکرد سیستم لجن فعال تلفیقی با بستر ثابت در تصفیه خانه فاضلاب شهرک صنعتی آمل (ایران- آمل)، در تصفیه فاضلاب صنایع غذایی مورد بررسی قرار گرفت. همچنین ضرایب سینتیکی این سیستم محاسبه گردید. گنجایش این سیستم ۱۷۰۰ مترمکعب در روز و شامل بخش های مختلفی مانند تصفیه فیزیکی و شیمیایی، گندزدایی، تغلیظ، آبگیری و هضم لجن است. در این مطالعه راندمان حذفCOD و ضرایب سینتیکی شامل ضریب بازده رشد (Y)، ثابت نیمه اشباع ($K_s$)، نرخ حداکثر مصرف سوبستره (k) و ضریب خودخوری ($K_d$) محاسبه گردید. نتایج نشان داد که به جز ($K_s$)، سایر ضرایب در محدوده نرمال گزارش شده برای سیستم لجن فعال متعارف است. راندمان حذف COD در حدود ۹۸ تا ۹۹ درصد بود. نتایج نشان داد که رابطه مستقیمی بین تغییرات $K_d$ و $K_s$ با غلظت سوبستره خروجی وجود دارد. در حالیکه رابطه بین k و سوبستره خروجی رابطه ای معکوس است. در نهایت تاثیر اثر زمان ماند سلولی (SRT) بر حذف مواد آلی مورد بررسی قرار گرفت. نتایج نشان داد با افزایش زمان ماند سلولی تا یک زمان مشخص، حذف COD افزایش می یابد و پس از آن تاثیر چندانی در راندمان حذف مشاهده نمی گردد.