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**Original Research Article**

# Development of Predictive Kinetic Models for the Biodegradation of Olusosun Dumpsite Leachate using Activated Sludge Process

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**ABSTRACT**

*Biodegradation of leachate generated from dumpsite before discharging to the environment is a way of preserving and sustaining the environment. The aim of this work was to develop kinetics for biodegradation of Olusosun dumpsite leachate in Lagos State using activated sludge process. Sludge of 2.5 L was seeded in a bioreactor and 25 L of collected leachate from Olusosun dumpsite was transferred into the bioreactor using a single stage centrifugal pump operated at 25 L/min. A retention time of 7 days was observed after which aeration was provided into the bioreactor and the content was stirred. Treated leachate sample were taken at hydraulic retention time (HRT) in variation between 2 and 14 hrs. The treated and untreated leachate samples were analysed for biochemical oxygen demand (BOD) and volatile suspended solids (VSS) according to standard methods for examination of water and wastewater prescribed by American Public Health Association/American Water Works Association /Water Environment Federation. The integrated form of the Monod and Modified Monod model were employed to determine the bio-kinetic coefficients which include maximum specific substrate utilization rate (K), half saturation coefficient ($K_s$), endogenous decay coefficient ($K_d$) and yield coefficient (Y). The bio-kinetic coefficients were then used to develop predictive kinetic models for bio-degradation of Olusosun dumpsite leachate. The results showed that the values of K, $K_s$, $K_d$ and Y were 1.0246 $hr^{-1}$, 27.001 mg/L, 0.0265 $hr^{-1}$ and 0.269 mgVSS/mgBOD respectively. The developed predictive kinetic model can be used to navigate Olusosun dumpsite leachate biodegradation process using activated sludge.*



## 1. INTRODUCTION

Leachate generated from dumpsite can easily cause havoc to the environment through pollution of soil, vegetation, surface and groundwater quality (Susu and Salami, 2011; Salami *et al.*, 2015; May – Marrufo *et al.*, 2017 and Ashish *et al.*, 2024). There are different ways of treating leachates depending on the type of pullutants to be treated. The organic pollutants in leachates can be treated by biological method which is the degradation of pollutants as a result of microorganism metabolic activities (Amin *et al*., 2021). Biological treatment of leachates using activated sludge processes is cost effective and is a viable process for reducing organic constitutes and toxicity (Qin *et al*., 2007).

Numerous works have been done on treatment of leachates using biological process (Okpokwasili and Nweke, 2005; Sperling, 2007; Mardani *et al*., 2011; Sushovan and Debasangham *et al*., 2021; Goswami *et al*., 2017; Musa *et al*., 2015 and Salami *et al*., 2021). Okpokwasili and Nweke (2005) reviewed the kinetic models for prediction of degradation of organic compounds and microbial growth. The review revealed that success of treatment process is a function of optimization of several controlling factors which determine the process rate. Mardani et al. (2011) worked on determination of the bio-kinetic coefficients for treatment of municipal wastewater using activated sludge process. The work showed that the yield coefficient, saturation constant, decay coefficient and maximum specific growth rate for convectional activated sludge process ranged between 0.48 and 0.8 mg VSS/mg COD, between 52 and 71 mg COD/L, between 0.189 and 0.026 L/day and between 0.95 and 0.98 L/day respectively.

Sushovan and Debabrata (2014) studied the kinetic coefficients for municipal wastewater treatment in aerobic hybrid bioreactor. The study stated the hybrid system is superior over a convectional aerobic bioreactor. Goswami *et al.* (2017) developed a method for determining the kinetic coefficients for aerobic biofilm bioreactor. The developed method for the determination of kinetic coefficients for an aerobic biofilm bioreactor was validated and the validation indicated that the developed method was fast, accurate and a simplified way to find out the kinetic coefficient of an aerobic biofilm reactor. Momob *et al.* (2020) investigated the kinetic coefficients of substrate utilization and biomass growth in the bio-degradation of petroleum refinery wastewater in an activated sludge process using Monod and the Modified Monod kinetic model. The investigation showed that the endogenous decay, half saturation constant, maximum substrate utilization rate and yield coefficient were 0.003 $day^{-1}$, 275 mg/L, 4.4 $day^{-1}$ and 0.5083 mg VSS/mg BOD respectively.

Sanghamitra et al. (2021) examined the kinetic coefficients for treatment of synthetic oily wastewater in suspended growth batch fed reactor. The examination revealed that the half saturation, yield coefficient, endogenous decay constant, maximum specific substrate utilization rate and inhibition constant were 96.5 mg/L, 0.75 mg VSS/ mg substrate, 0.0012 $day^{-1}$, 0.197 $day^{-1}$ and 120 mg/L respectively. It is obvious that the kinetic coefficients for treatment of Olusosun dumpsite leachate using activated sludge process are not available from myriad of literature. Therefore, the aim of this work is to develop predictive kinetic models for bio-degradation of Olusosun dumpsite leachate using activated sludge process with a view of making available the kinetic coefficients for treatment of Olusosun dumpsite leachate using activated sludge process. The predictive kinetic models will be very useful for proper understanding of dynamic substrate utilization involving production of biomass and for the efficient design of biological leachate treatment system which justifies this work.

## 2. MATERIALS AND METHODS

### 2.1. Experimental Procedure

A bioreactor was seeded with 2.5 L of collected sludge and 25 L leachate taken from Olusosun dumpsite in Lagos State was pumped into the bioreactor with the aid of a single stage centrifugal pump operated at 25 L/min. A sludge retention period of 7 days was allowed for the microorganisms in the system to acclimatize. Air compressor operated at 100 L/min was used to provide aeration into the bioreactor. After acclimatization, mechanical stirrer operated at 500 rpm was used to stir the content of the bioreactor for hydraulic retention time (HRT) of 2 hrs. The content was then allowed to flow into a settling tank where settling took place for 1 h, sample of the treated leachate was taken and labeled TL 1. The remaining content in the settling tank was transferred back to the bioreactor. The same procedure was carried out at HRT of 4, 6, 8, 10, 12 and 14 h and the collected treated leachate samples were labeled TL 2, TL 3, TL 4, TL 5, TL 6 and TL 7 respectively. All the treated leachate samples and untreated leachate were transferred to laboratory for analysis of biochemical oxygen demand (BOD) and volatile suspended solid (VSS) according to the standard methods prescribed by APHA/AWWA/WEF (2017) for examination water and wastewater.

**2.2. Kinetics and Mechanism of Activated Sludge Process**

The maximum specific substrate utilization rate shown in Equation (1) was substituted into Equation (2) (Monod kinetic equation) which presented the rate of substrate concentration change due to utilization to obtain Equation (3) that revealed the relationship among rate of substrate concentration change, maximum specific growth rate and yield coefficient.

$$K = \frac{\mu_{max}}{Y} \quad (1)$$

Where *K* is the maximum specific substrate utilization rate, $\mu_{max}$ is maximum specific growth rate and *Y* is yield coefficient.

$$r_{su} = \frac{ds}{dt} = \frac{KSX}{K_s + S} \quad (2)$$

Where $r_{su}$ = rate of substrate concentration change due to utilization, S – substrate (BOD) concentration, $K_s$ = half saturation coefficient and *X* = biomass (microorganism concentration) which is the concentration of VSS.

$$r_{su} = \frac{\mu_{max} S X}{Y(K_s + S)} \quad (3)$$

The rate of substrate utilisation in Equation (3) was substituted in Equation (4) which depicted the relation of specific growth rate to substrate utilisation to obtain Equation (5) that relates substrate concentration and the microbial growth.

$$\mu = Y \frac{r_{su}}{X} \quad (4)$$

Where $\mu$ = specific growth rate

$$\mu = \mu_{max} \frac{S}{K_s + S} \quad (5)$$

The microbial death rate of Equation (6) and substrate utilisation rate of equation (3) were put in the net rate growth of Equation (7) (Modified Monod model) to yield Equation (8).

$$-r_d = K_d(X) \quad (6)$$

$$r_g = (Y)(r_{su}) - K_d(X) \quad (7)$$

$$r_g = \frac{\mu_{max} S X}{K_s + S} - K_d(X) \quad (8)$$

The net rate of growth of Equation (8) was inserted in specific biomass growth rate of Equation (9) which produced the net specific growth rate of Equation (10).

$$\mu = \frac{r_g}{X} \quad (9)$$

$$\mu = \mu_{\max} \frac{S}{K_s + S} - K_d \quad (10)$$

Using Equation (1), Equation (10) was written as Equation (11).

$$\mu = Y \frac{K_s}{K_s + S} - K_d \quad (11)$$

The Monod kinetic model (Equation 2) and Modified Monod kinetic model (Equation 7) were integrated to obtain the integrated form of Monod and Modified Monod kinetic model presented in Equations (12) and (13) respectively.

$$\frac{X\theta}{S_o - S} = \frac{K_s}{K}\frac{1}{S} + \frac{1}{K} \quad (12)$$

$$\frac{1}{\theta} = \frac{S_o - S}{X\theta} Y - K_d \quad (13)$$

Where $\theta$ is the hydraulic retention time and $S_o$ is the initial substrate concentration.

A plot of $\frac{X\theta}{S_o - S}$ against $\frac{1}{S}$ was carried out to determine $K$ and $K_s$. A graph of $\frac{1}{\theta}$ against $\frac{S_o - S}{X\theta}$ was also plotted to evaluate $K_d$ and $Y$. The food – to – microorganism ratio was determined using Equation (14).

$$\frac{F}{M} = \frac{S_o}{X\theta} \quad (14)$$

## 3. RESULTS AND DISCUSSION

### 3.1. Microbial Growth and Substrate Utilisation

Substrate utilization leads to removal of pollutants which in turn results to increase in microbial biomass and bio-degradation of organic pollutants (Okpokwasili and Nweke, 2005). Figure 1 shows cell growth and substrate utilization against HRT. BOD which is the substrate considered in this work was degraded from 102 to 13.95 mg/L at HRT of 14 hrs. The biomass growth increased from 13 to 49.35 mg/L at HRT of 14 hrs. This revealed that the microorganism present in the collected sludge were capable of biodegrading the organic pollutants in Olusosun dumpsite leachate. Figure 2 depicts the food – to – microorganism ratio at different HRT. The food – to – microorganism ratio indicated how much food was available at various HRT. It decreased as HTR increased which was in line with the previous work of Momoh *et al.* (2020).

Maximum specific rate of substrate utilization is a very useful parameter for the design of reactor volume in biological leachate treatment process (Benefield and Randall, 1980). The higher the value of maximum specific rate of substrate utilization, the smaller the size of the bioreactor that will be needed for treatment of wastewater (Momoh *et al.*, 2020). The value of $K$ obtained in this work was 1.0246 $hr^{-1}$ which is higher than the value of 0.185 $hr^{-1}$ reported by Zhong et al. (2003) for treatment of wastewater from petroleum industry but less than the values of 4.4 and 0.274 $day^{-1}$ obtained in the works of Momoh et al. (2020) and Andress et al. (2011) respectively for the treatment of wastewater from petroleum industry.

This is an indication that the *K* value for dumpsite leachate treatment using biological method is likely to be higher than the *K* value for treatment of wastewater from petrochemical industry but less than the *K* value for petroleum industry. This variation may be attributed to the fact that various wastewaters have different characteristics.

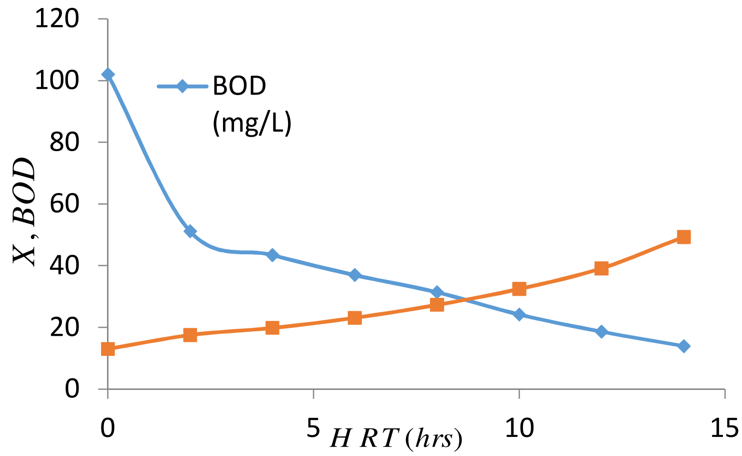


Figure 1: Biomass growth and substrate utilization

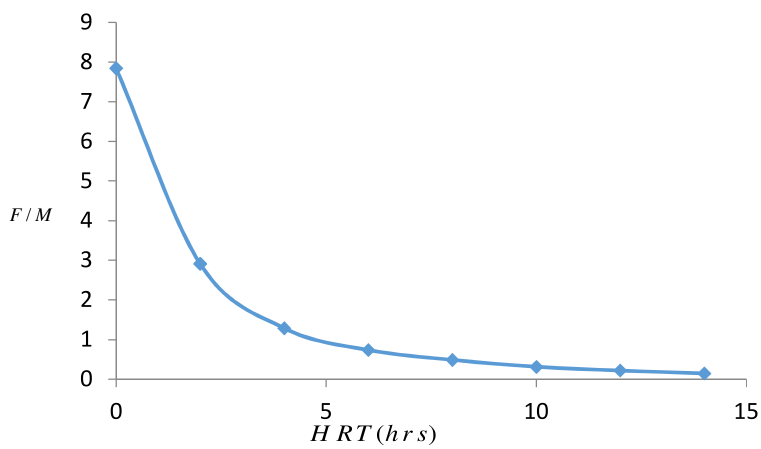


Figure 2: Food – to – Microorganism ratio

### 3.2. Evaluation of Bio-kinetic Coefficients

Figures 3 and 4 present a plot of integrated form of Monod and Modified Monod model which were used to determine the bio-kinetic coefficients for treatment of Olusosun dumpsite leachate using activated sludge process. In Figure 3, the goodness fit ($R^2$) value was 0.8794 which implied that the line of best fit explained 87.94 percent of the experimental data hence the intercept was used to evaluate *K* which was obtained to be 1.0246 $hr^{-1}$ and the slope was used to determine $K_s$ which was found to be 27.001 mg/L. In Figure 4, the $R^2$ value was 0.9984 which indicated that the line of best fit explained 99.84 percent of the experimental data. The intercept of the plot was used to calculate $K_d$ $hr^{-I}$ to be 0.0265 and *Y* was evaluated to be 0.269 mg VSS/mg BOD from the slope of the graph.

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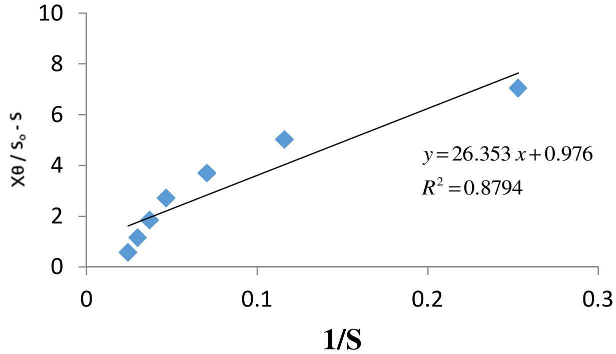


Figure 3: A plot for determination $K$ and $K_s$

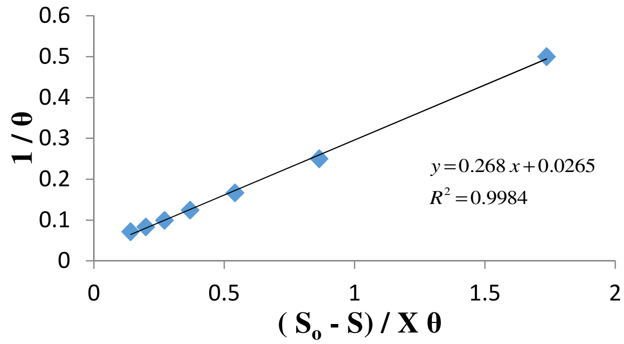


Figure 4: A plot for determination $K_d$ and $Y$

Half saturation coefficient is the concentration which supports the uptake rate of one – half of the maximum rate. It is the substrate concentration at which substrate utilization is equivalent to half of maximum rate of substrate. It is inversely to specific growth rate and approximately varied proportional to cell size. Half saturation coefficient is synonymous to Michaelis constant in Michaelis Menten model, which is the concentration of the substrate when the reaction velocity is 50 percent of the maximum. The $K_s$ obtained in this work was 27.001 mg/L. According to Benefield and Randall (1980) as stated by Momoh *et al.* (2020), $K_s$ gives an understanding about change in specific growth limiting microorganism when there is a change in growth limiting substrate concentration but has no direct importance in process design of treatment of wastewater. It can also be deduced that there no direct correlation between maximum specific rate of substrate utilization and half saturation coefficient as evident in Table 1. Table 1 presents shows the bio-kinetic coefficients obtained in this work in comparison with previous works of scholars while Table 2 presents the predictive model for biomass growth and substrate utilization for treatment of Olusosun dumpsite leachate using activated sludge process.

Yield coefficient also refers to as biomass yield is a stoichiometric coefficient which characterizes the growth efficiency of a microbial strain. It shows how much biomass can grow per quantity substrate energy consumed (Adiandri *et al.*, 2021). It measures the biomass produced with respect to substrate utilized. The yield is a very important parameter in the process design because it gives insight on the estimation of sludge produced in leachate treatment. The biomass yield in this study was 0.269 mg Vss / mg BOD. The results of the works of Haydar and Aziz (2009) and Momoh *et al.* (2020) showed a biomass yield of 0.64 for ternary wastewater treatment and 0.5083 mg VSS / mg BOD for petroleum wastewater treatment respectively. This indicated that different wastewater treatments have various yield which can be attributed to different wastewater having different composition and characteristics.

Table 1: Bio-kinetic coefficient of previous works in comparison with the present work

| Wastewater | *K* ($day^{-1}$) | $K_s$ (mg/L) | *Y* (mg VSS) / mg COD | $K_d$ ($day^{-1}$) | References |
|---|---|---|---|---|---|
| Municipal | 0.95 – 0.98 | 52.71 - 71 | 0.48 – 0.8 | 0.0189 – 0.026 | Mardani *et al.* (2011) |
| Ternary | 3.125 | 488 | 0.64 mg VSS /mg BOD | 0.035 | Haydar and Aziz (2009) |
| Petroleum | 0.185 $hr^{-1}$ | 154 | - | - | Zhong *et al.* (2003) |
| Petroleum | 0.274 | 165.8 | 0.424 | 0.01 | Andress et al. (2011) |
| Dairy | 4.46 | 534 | 0.714 | 0.038 | Ambreen et al. (2013) |
| Ternary | 1.66 | 1132 | 0.22 | 0.05 | Prakash and Sockan, (2014) |
| Petroleum | 9.31 | 162.4 | 0.8896 | 0.1284 | Talaiekhozani *et al.* (2015) |
| Petrochemical | 0.0197 | 96.5 | 0.75 | 0.0012 | Sanghamitra and Debabrata (2021) |
| Petroleum | 4.4 $hr^{-1}$ | 275 | 0.5083 mg VSS / mg BOD | 0.003 | Momoh *et al.* (2020) |
| Leachate | 1.0246 $hr^{-1}$ | 27.001 | 0.269 mg VSS / mg BOD | 0.0265 $hr^{-1}$ | Present swork |

Table 2: Predictive models for bio-degradation of Olusosun dumpsite leachate

| Parameters | Model | Predictive Model |
|---|---|---|
| Substrate Utilisation | $r_{su} = \frac{ds}{dt} = \frac{KSX}{K_s + S}$ | $r_{su} = \frac{ds}{dt} = \frac{1.0246\,SX}{27.001 + S}$ |
| Maximum bacteria growth rate | $\mu_{max} = KY$ | $\mu_{max} = 0.2756$ |
| Bacteria growth rate | $\mu = \mu_{max} \frac{S}{K_s + S}$ | $\mu = 0.2756 \frac{S}{27.001 + S}$ |
| Microbial death rate | $-r_d = K_d (X)$ | $-r_d = 0.0265 (X)$ |
| Net biomass production rate | $r_g = Y \frac{KSX}{K_s + S} - K_d (X)$ | $r_g = 0.269 \frac{1.02465\,SX}{27.001 + S} - 0.0265 (X)$ |
| Bacterial growth rate in term of yield | $\mu = Y \frac{S}{K_s + S} - K_d$ | $\mu = 0.269 \frac{S}{27.001 + S} - 0.0265$ |

The higher the biomass yields the greater the quantity of sludge that will be produced. Endogenous decay coefficient explains the loss in quantity of cell as a result of oxidation of the internally stored products to release energy for cell death and cell maintenance. It is the fraction of oxidized cell due to endogenous respiration per unit time. It is a very useful stoichiometric coefficient for understanding the activities of microbes during leachate treatment processes (Ezerie *et al.*, 2015). The endogenous decay coefficient in this work was 0.0265 $hr^{-1}$ which translated to 0.0011 $day^{-1}$. The decay coefficient in the works of Momoh et al. (2020), Talaiekitra and Debabrata (2021) were 0.003, 0.1284 and 0.0012 $day^{-1}$ respectively. A low decay coefficient means a low decay of microorganisms hence a decay rate of 0.0011 $day^{-1}$ obtained in this work implied low number of microorganisms were decayed during the leachate treatment process. $K_d$ can be used to evaluate the net sludge production in the activated sludge process and gives an insight on the size of the sludge handling facility that would be required for treatment process system.

## 4. CONCLUSION

The development of predictive model for biodegradation of Olusosun dumpsite leachate using activated sludge process has been carried out. The bio-kinetic coefficients were obtained using Monod and Modified Monod model. The maximum specific rate of substrate utilization which determines the reactor volume in the biological leachate treatment process was 1.0246 $hr^{-1}$. The half saturation coefficient which provides the understanding about change in specific growth rate of microorganisms when there is a variation in growth limiting substrate concentration was 27.001 mg/L. the yield coefficient that gives information concerning the characteristic about the growth efficiency of a microbial strain was 0.269 mg VSS/ mg BOD. The endogenous decay coefficient which accounts for loss of cell due to oxidation of the internally stored product for release of energy was evaluated to be 0.0265 $hr^{-1}$. The obtained biokinetic coefficient provided proper understanding of the dynamic of substrate utilization involving biomass production for the treatment of Olusosun dumpsite leachate using activated sludge and can be used for efficient design of biological leachate treatment system. Hence the developed predictive models can be used to navigate the treatment process of Olusosun dumpsite leachate using activated sludge process.

## 5. ACKNOWLEDGMENT

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## 6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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