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***Research Article***

# SPECIFIC MICROBIAL DEGRADATION KINETICS OF FOOD WASTE: A CASE STUDY

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## ABSTRACT
A bench scale study has been carried out for the anaerobic microbial decomposition of food waste produced by the mess of the campus of an engineering college in Jalgaon ($21^0$N, $75.56^0$E). The kinetic coefficients of the waste namely half velocity constant, maximum substrate utilization rate, maximum specific growth rate coefficient, decay coefficient, and yield coefficient are determined. The coefficients are determined using the kinetic model given by Monod (1949) and the linear regression techniques. There are five bench reactors used in parallel for higher reliability of the experimental data. COD (Chemical oxygen demand) and VSS (Volatile suspended solids) are used as indicators for the steady state. After achieving the steady state, data is analyzed by linear curve fitting techniques. The coefficient of regression is found to be 0.92 which is quite high and satisfactory. These coefficients provide a scientific and logical deep insight into the biochemical phenomenon going on during the process of decomposition by anaerobic microorganisms and pave a path for rational understanding, analysis and design of the anaerobic bioreactor.

***Key Words:*** *Anaerobic Digestion, Bench Scale Reactor, Kinetic Coefficients, Linear Regression*

## INTRODUCTION
The dawn of the third millennium has come up with new horizons and new challenges. The previous century was for the search of knowledge, the present century is for the management of knowledge. With the tremendous development in science and technology followed by industrialization, population explosion and changed life style, few new challenges are being faced by the civilization (Pachauri *et al.*, 2008). The fossil fuel had been the principal source of energy till now. Yet it has created gigantic pollution havoc in terms of global warming and climatic pattern changes. Moreover the limited resources of fossil fuel are at the verge of vanishing. Thus the civilization requires new sources of energy those are environmental friendly too.

Energy from food waste is an eternal source as it will last till the civilization will exist (Tchnobonoglous *et al.*, 1993). Food waste is digested by microorganisms under anaerobic environment and methane is the product of concern. This methane has calorific value and can be used for cooking, lighting and even for electricity generation (Whittington, 2002; Kaplan *et al.*, 2009; Lohila *et al.*, 2007). The anaerobic decomposition of organic waste is a phenomenon that has been explored by several researchers (McCarty, 1964; McCarty, 1966; Holland *et al.*, 1987; Nwabanne *et al.*, 2009; Xian *et al.*, 2012). In fact researchers had been working on the anaerobic digestion since from the beginning of the twentieth century (Metcalf and Eddy, 1991). Earlier researcher considered the microbial decomposition process as more or less a black box like phenomenon. However kinetic theory gradually penetrated into the phenomenon.

Tissier, Contois and Moser (Stanier *et al.*, 1986) have proposed few mathematical models that give a rational insight into the microbial decomposition process. Some of them about the rate of substrate utilization are listed below:

$r_{su} = -k$ (1)

$r_{su} =-Ks$ (2)

$r_{su} = -kXS$ (3)

$r_{su} = -kXS/S_0$ (4)

Where, $r_{su}$ is rate of substrate utilization, $k$ is maximum rate of substrate utilization, $S_0$ and $S$ are initial substrate concentration and substrate concentration in reactor, $X$ is biomass concentration in the reactor.
The expressions from (1) to (4) consider the reaction rate as constant, linear function of substrate concentration, and function of substrate concentration and microbial concentration. All of them have limited scope. The most widely used form of the expression is given by Monod (1949):

$$\mu = \mu_m(S/K_s + S) \quad (5)$$

Where, $\mu$ and $\mu_m$ respectively represent specific growth rate and maximum specific growth rate, $K_s$ refers to the half velocity constant. The Monod's theory is quite comprehensive and it has been used most widely by the researchers. In fact it is the most rational representation of the microbial decomposition process in the mathematical form. The present work has also used the same expression for determination of kinetic coefficients.
The kinetic theory is a rational and mathematical approach of describing what is going on in a bioreactor. The theory is developed by defining following five kinetic coefficients: $\mu_m$, $K_s$, $Y$, $k$, and $k_d$. They are defined as follows: $K_s$ = substrate concentration corresponding to the half of the maximum specific growth rate, mg/L
$\mu_m$ = maximum specific growth rate coefficient, per day
Y = yield coefficient, biomass generation per unit substrate utilization, dimensionless
$k_d$ = decay coefficient of microorganisms, per day
$k = \mu_m/Y$.
The kinetic coefficients defined above are specific to the waste characteristics, environmental conditions and microbial species. However, a particular waste and a particular environmental condition are most conducive for the sustainability of a specific species of the microbes. These species will be a mixed culture of microorganisms which will be established after initial transitions. Once the transitions are over, the steady state is arrived. It is to be worth noting that the models being discussed herein are applicable to the steady state only. The kinetic coefficients give a deep insight into the biochemical/microbial process going on and enable to rationally analyze and design the bio reactors using kinetic theory. Now a day, the kinetic theories are being most widely used in the design and analysis of waste treatment systems. In fact the modern design of a waste treatment facility involves three steps:
1. Determination of kinetic coefficients through bench scale studies.
2. Determination of loading parameters by pilot plant studies.
3. Design of reactor using kinetic models.
The present research work is concerned with first stage that is determination of kinetic coefficients for the food waste of the residential campus of the College of Engineering and Technology, Bambhori, Jalgaon, MS. These coefficients will be subsequently used for the design of anaerobic digester for the campus and gas will be used for the energy generation. For determination of coefficients, Monod's equation is applied to the case of a continuously mixed reactor as shown in the figure 1. The reactor resembles to the most common case of a bioreactor.

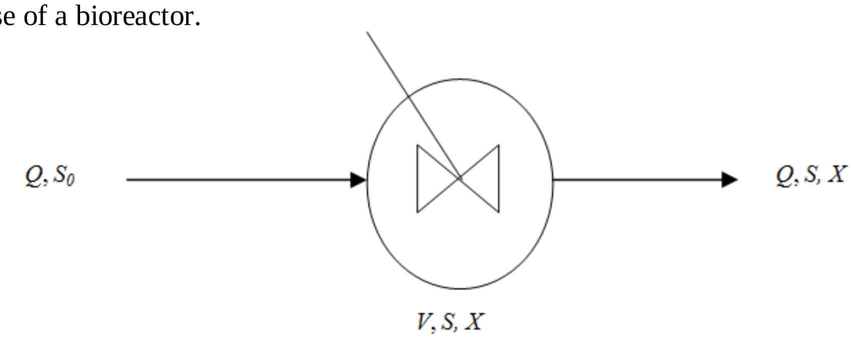


**Figure 1: Schematic of a complete mix reactor without recycles**

The kinetic theory is applied to the case of figure 1 by writing equations for rate of substrate utilization ($r_{su}$) and rate of growth of microorganisms ($r_g$) and applying conditions of mass balance at inlet and outlet of the reactor. With due adjustments, following two equations are obtained:

$$X\theta_c/(S_0 - S) = K_s/kS + 1/k \quad (6)$$

$$1/\theta_c = Y(S_0 - S)/\theta_c X - k_d \quad (7)$$

The equations (6) is linear with variables $K_s/k$ and $1/k$, while (7) with $Y$ and $k_d$. The values of $S_0$ (Initial substrate concentration) is already known, whereas the $S$ (effluent substrate concentration), $X$ and $\theta_c$ are determined from experimentation. Each of the equations can be solved by just two sets of known quantities, obtained by experimentation. However, in the present work, five sets of the experimental setups are used. The unknowns (coefficients) are determined by linear regression techniques for higher precision of results.

## MATERIALS AND METHODS

### *Experimental Method*

The present work is a case study for food waste generated by the mess of COET, Bambhori. The waste is quantified and characterized as per the process described by the Flintoff (1972). The methane generation potential of the waste is also estimated. The results are published in Parag *et al.*, (2013). The experimental setup is schematically represented in figure 2.

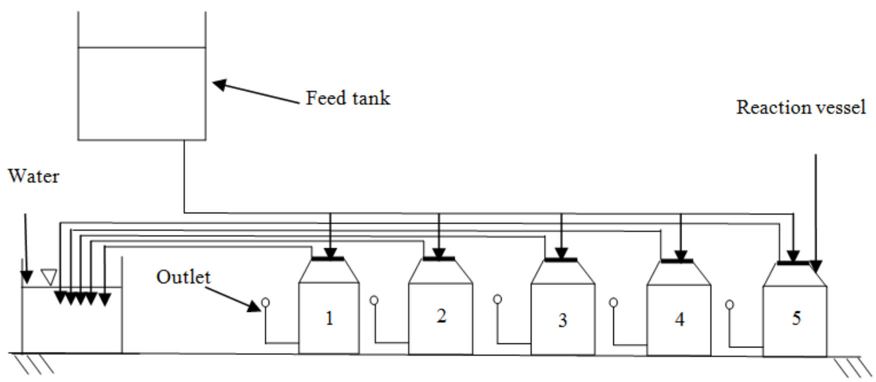


**Figure 2: Schematic representation of experimental setup of bench scale reactor for determination of kinetic coefficients**

There are five glass vessels each of capacity 2 L. They are connected with a feed tank in which pulverized food waste is mixed with water in slurry form. The food waste in bulk quantity is collected from the source, pulverized and stored in deep freeze. Every day the same waste is used thus ensuring the constant input quality. The slurry is prepared with 50 g/L solid waste. It is fed to each of the glass made reaction vessel with 1.5 L slurry. Each vessel is inoculated with 20 mg/L seed collected from a working anaerobic reactor. Now, they are fed with food slurry every day, prepared as described above. The dose of slurry for reaction vessels no. 1 to 5 varied from 25mL to 45 mL in steps of 5 mL. The following parameters of the effluent collected from the vessel outlets are monitored: pH, TSS, VSS, COD, and TKN (Total kjeldahl nitrogen). Out of these parameters, the relevant ones are the pH, VSS and COD for kinetic coefficient determination and they are shown here. The monitoring is continued till the steady state has been achieved. The parameters are determined at every fifth day. Every time from every vessel, three samples are collected and analyzed separately. Their average values are also determined. The gasses produced during the process are drained out in the water seal arrangement as shown in the figure 2. The arrangement allows gas drain but does not allow air to enter into the vessel, which may be toxic to the microbes.

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## RESULTS AND DISCUSSION

The various parameters as mentioned above of the reaction vessel effluents are monitored to determine the steady state. The parameters are monitored during March 14, 2013 to May 9, 2013; that is for duration of 57 days. The steady has (constant effluent COD) was observed at this duration. The variation of parameters for the five reaction vessels is shown in figure 3-5. The samples are analyzed at an interval of five days for 57 days. The vertical lines in the figures represent the variation in the averaged out value of three samples analyzed simultaneously.

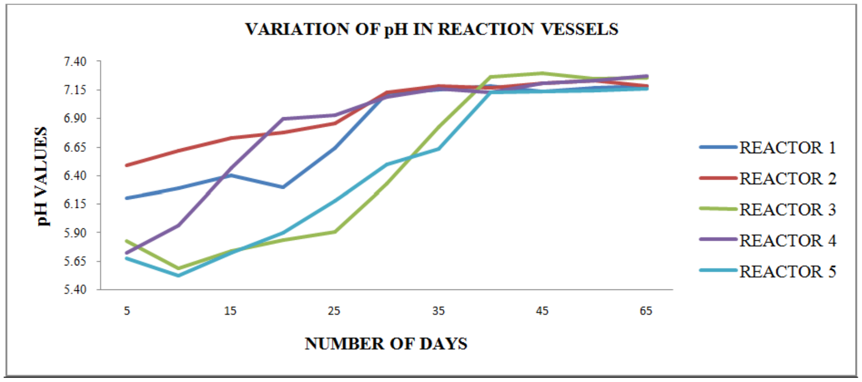


**Figure 3: Variation of pH with time**

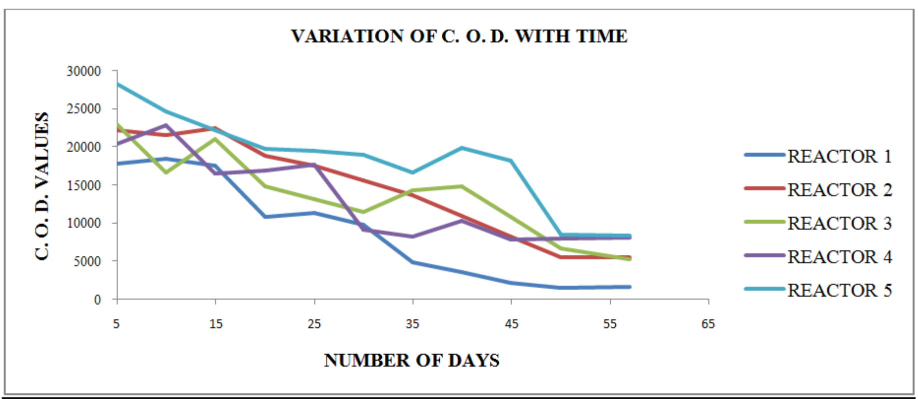


**Figure 4: Variation of COD with time**

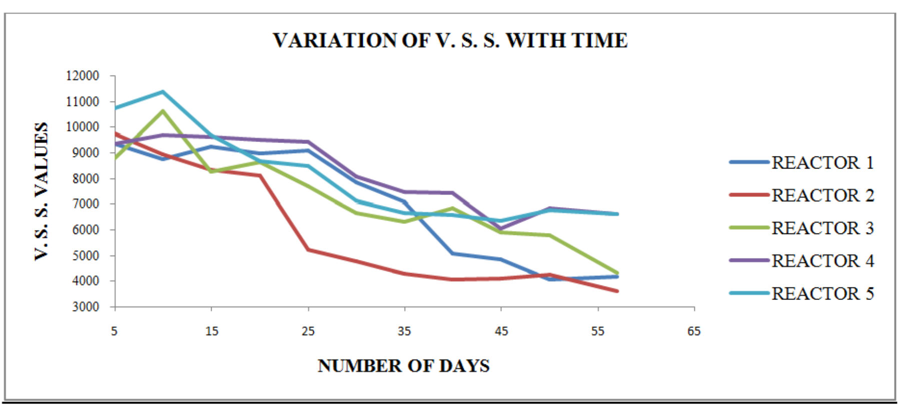


**Figure 5: Variation of VSS with time**

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Figure 3 shows the variation of pH with time. It can be seen that the pH has reached from acidic range to the neutral range with time. This may be attributed to the formation of ammonia in the process of degradation as the waste is rich in terms of Total kjeldahl nitrogen and the anaerobic microbes have a less uptake of nitrogen.

Figure 4 shows the variation of COD. It can be seen that the COD which is very high, in the range of >25000 mg/L has been reduced to the range of 2 to 5 thousand mg/L. The variation of COD has slashed down to minimal at around 30 days and is indicative of steady state. The steady state has arrived in quite a reasonable time. This is because of the fact that the reaction vessels were inoculated with seed from a working anaerobic digester. Thus the microbes were activated and acclimatized and they could easily and promptly adapt to the environment of reaction vessel. The similar observations can be drawn from figure 5 also which depicts the variation of VSS with time. VSS is a measure of microbial density in the system. The steady state data is summarized in table 1 below.

**Table 1: Steady state observation from reaction vessels**

| **Reactor No.** | **Input substrate concentration Measured as COD, mg/L ($S_0$)** | **Effluent substrate concentration Measured as COD, mg/L ($S$)** | **Cell residence time in days ($\theta_c$)** | **VSS, mg/L ($X$)** |
|---|---|---|---|---|
| 1 | 17902 | 1634 | 60 | 4054 |
| 2 | 22189 | 5590 | 50 | 3528 |
| 3 | 22956 | 5749 | 43 | 4290 |
| 4 | 20468 | 8394 | 37 | 6653 |
| 5 | 28316 | 8554 | 33 | 6567 |

The reaction vessels are without re-circulation hence, cell residence time is same as hydraulic retention time = volume of reaction vessel/rate of flow (feed volume). The table 1 data is used to generate table 2 data which is required by equation (6) and (7).

**Table 2: Calculations for equation (6) and (7)**

| **Reactor No.** | **$S_0 - S$ *(col no. 2)*** | **$X\theta_c / (S_0 - S)$ *(col no. 3)*** | **$1/S$ *(col no. 4)*** | **$1/\theta_c$ *(col no.5)*** | **$(S_0 - S) / X\theta_c$ *(col no. 6)*** |
|---|---|---|---|---|---|
| 1 | 16268 | 16.61 | 0.0061 | 0.016 | 0.060 |
| 2 | 16599 | 14.17 | 0.0017 | 0.020 | 0.070 |
| 3 | 17207 | 16.75 | 0.0017 | 0.023 | 0.060 |
| 4 | 12074 | 36.73 | 0.0019 | 0.027 | 0.027 |
| 5 | 19762 | 22.15 | 0.0016 | 0.030 | 0.045 |

Equation (6) and (7) can be compared with the linear forms as:

$$y = mx + c \tag{8}$$

Comparing equation (8) with (6), $m = K_s/k$ and $c = 1/k$. Using linear curve fitting techniques (Chapra *et al.*, 2009), $m = (n\Sigma xy - \Sigma x\Sigma y)/[n\Sigma x^2 - (\Sigma x)^2]$. For equation (6), $x$ and $y$ respectively resemble to column no (3) and (4) values. Using these values, $m = K_s/k$ is found to be 257.75 and substituting value of $m$ in equation

(6), $c = 1/k$ is found to be = 7.21. Thus, values of $k$ and $K_s$ are found. Similarly, comparing equation (8) and (7) and solving in the same way, we find values of $Y$ and $k_d$.
Thus the five kinetic coefficients are determined as follows:
$K_s$ = 35.75 mg/L, substrate concentration corresponding to the half of the maximum specific growth rate,
$\mu_m$ = 0.081 per day, maximum specific growth rate coefficient,
Y = 0.42, dimensionless, yield coefficient, biomass generation per unit substrate utilization,
$k_d$ = 0.027 per day, decay coefficient of microorganisms,
$k$ = 0.138 per day.

***Conclusion***

The kinetic coefficients are the tools for scientific and rational analysis of microorganism driven biochemical processes. They give a mathematical insight into the processes. They are incumbent for the rational analysis and design of bioreactors. The old approach of designing the bioreactors using empirical formulations and thumb rules or designing purely based upon pilot plant bases are obsolete now. The modern approach is to design the bioreactors using kinetic theory. Thus the kinetic coefficients determined in the present research work will pave the path for rational design of a full-fledged anaerobic digester for the residential campus of College of Engineering and Technology, Bambhori, Jalgaon. The digester thus designed will be more transparent in terms of technology and will give better operating controls in the hands of engineers. The coefficients thus generated shall be useful for similar cases of other residential campus also in the region.

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