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Investigation on Characteristics of Potato Waste Degradation in an Anaerobic Digester: The influence of pH

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ABSTRACT

Investigation was conducted to examine potato waste degradation using experimental and mathematical formulation to monitor the degradation of the potato solid waste in an anaerobic bio-digester. The effect of P^H on the potato waste degradation as well as the contribution towards the determination of the kinetics parameters was evaluated using Michael's Mentene model approach. The concept of Taylor's variables was applied in the determination of the functional parameters and the results obtained revealed that pH is a contributing factor in the degradation of potato waste in an anaerobic digester.

Key word: Investigation, characteristics, potato waste, degradation, anaerobic digester, influence, pH

1. INTRODUCTION

The investigation on solid waste degradation is found necessary because of the usefulness of products obtained after complete reaction in an anaerobic digester. The toxic wastes also called hazardous wastes are poisonous which its byproducts are obtained from the reaction mechanism of the chemistry of the process. The Toxic waste can be grouped in terms of liquid, solid or gas form and this can cause harm when being inhaled, swallowed or absorbed through the skin (Vaughn, 2013). The toxic waste can be harmful to health and they comprise of the old medicines, paints, chemicals, fertilizers and pesticide containers, batteries, etc.

Recyclable wastes are waste that can be reformed to form other products. It means turning the materials from waste into something new (Barlaz, 1998). Some examples of the recyclable products are paper, metals, aluminum, plastics etc. The solid waste can be any material such as hospital waste (Fontaine, 2003). Example of the solid waste include clothe soiled with blood and other body fluid or other industrially solid materials.

Generally, the composting of domestic (municipal) solid waste varies from one waste to another. For example, the food samples such as fish gills, grape, cabbage, vegetable stem, etc as adopted in research work have been found to decompose between intervals of one to three weeks. From chemistry, the substrate is simply chemical specie being observed in a chemical reaction. It tells us that the substrate reacts with reagents to generate a product. While in synthetic and organic chemistry, the substrate is the chemical of interest that is being modified (Cravatt et al., 2001). But in biochemical engineering view, the substrate is a substance acted upon by the microorganism or enzyme. As the substrate is acted upon by the enzyme, the substrates attach themselves to the spatial binding sites of the enzyme to form an enzyme-substrate complex and the sites called the activation centers of the enzyme. A decomposition reaction is a type of chemical reaction in which a single compound breaks down into two or more elements or new compounds. These reactions involve an energy source such as heat, light or electricity etc., (Derrick, 2013).

The solid waste is attacked by microorganisms called the saprophytic microorganism. This microorganism usually depends and feed upon dead organic matters. Generally, the activity of such organisms causes decomposition of the organic matter by destroying them. For example, when the bacteria are in contact with the waste, it converts the waste or other constituents in the waste into new cells, water, gases and other products. The anaerobic process of the domestic solid waste is a process which involves the absence of oxygen as a state in the decomposing process. Lactic acid is usually created in anaerobic process.

2. MATERIALS AND METHOD

Materials, Equipment and Reagents used for the Research work

The materials, equipment and reagents used in this experimental work include: a batch reactor for anaerobic set-up, a glass measuring cylinders, a 60 inches host connected to reactor and measuring cylinder, retort stand on which the glass measuring cylinder was clamped, P^H meter for measurement of the concentration and acidity of the sample decomposition, P^H electrodes permanently fixed in the air tight (anaerobic) batch reactor, weighing balance, beakers, sample (domestic potato solid waste);

The P^H Meter

A P^H meter is a scientific instrument that measures the hydrogen-ion concentration or P^H in a solution which signifies the acidity or alkalinity of the given solution. Immediately after an experimental set up, the P^H meter is usually used to read the acidic range of the domestic solid wastes measured in mole/litre.

Weighing Balance

The weighing balance is used in measuring the respective weights/weight losses of the samples. In the experiment, the reactors were weighed in the weighing balance after carefully detaching the measuring cylinders attached to the reactors.

Sample Collection

The sample such as potato was obtained in averagely large quantities from different locations in Port Harcourt, Rivers State and transported to the Department of Chemical/Petrochemical Engineering Laboratory in Rivers State University Port Harcourt for onward analysis and experimental set up.

Experimental Procedure

Step 1: The weight and volume of the bioreactor was measured as 90g and 2600ml respectively. The samples was originally weighed equal with a weight of 635g each and fed into each of the bioreactor whose cock was alongside weighed. The bioreactor was further fed with 40% of 2600ml water which amounted to 1040g. Hence, the bioreactor has an initial sample weight of 1672g and concentration of 643.1g/l. And to obtain the accurate parameters of the experiment, the bioreactor cork was threaded and the P^H

electrode, thermometer and the 60 inches host inserted through the cork into the bioreactor. While the P^H electrode and thermometer was kept and read from the P^H meter, the 60 inches host was fixed into the 100ml measuring cylinder to trap any gas which escaped from the bioreactor. After insertion of the device, every opening in the bioreactor cork as well as in the measuring cylinder was lagged to avoid air leakage since the bioreactor is a closed system of an anaerobic process. The weight loss values were read from the weighing balance and converted to concentration whereas the temperature and P^H readings read from the P^H meter system with all the recordings made at every two days interval. On the first day, that is zero day of the experiment, the total weight (mass) of the experimental set up was noted as 2175g with the summary of the components and accessories of the total weights shown below;

Summary

Total weight of samples
Weight of water = 1040g
Weight of each sample = 632g
Total weight of sample =1672g
Total Weight of component = 503g

Total weight of components
Weight of empty bioreactor + Cork = 90g
Weight of lagged material = 100g
Weight of measuring cylinder + host = 313g

Total weight of sample + components on (0 Day for every sample)
Weight of sample = 1672g
Weight of components = 503g
Total weight of sample + components = 2175g

For the weight loss determination after every two days interval, the present total weight loss is subtracted from the initial total weight. And at the end of the 30 days experiment, the total component weight which is constant is noted and also subtracted from the initial total weight. Thus, the readings of the experimental set up were taken at the fresh compost stage, mature compost stage and the final compost stage of the sample.

Step 2: Reading of the weight loss using the weighing balance, the P^H value using the P^H meter and the temperature using the thermometer were taken for a period of thirty days on every two days interval from the day of the set-up of the experiment. While the temperature and P^H values were taken from the P^H meter system by inserting the thermometer and the P^H meter knob into the anaerobic reactor through the reactor cover, the weight loss was taken by carefully placing the reactor and its components on the weighing balance with a subtraction finally made between when the reactor had the sample and the component and when the sample was absent in the reactor. At the end of the thirty days experiment, the extract (liquid) of the sample was taken and sent to the biological laboratory for test for purpose of identification, isolation characterization of the possible microorganism capable of degradating the potato waste.

Isolation and Identification of Microorganisms

From the biological analysis carried out on the liquid extracts (liquid substances obtained at the end of the degradation of the domestic potato waste in the bio reactor and this process was carried in the Biological Laboratory, the various microorganisms responsible for degradation of the domestic potato solid waste was isolated and identified. This analysis was carried out in the Rivers State University Biological Laboratory by diluting the sample (extract) through a medium called ten-fold serial dilution. Csuros, (1999). Then, aliquot of 0.1ml of the last two dilutions were taken and plated differently and in duplicates using nutrient agar (NA) plates and potato dextrose agar (PDA) plates. The inoculated NA and PDA plates were incubated at 37 ˚C for 24 hrs and72 hrs respectively. Finally, to calculate the different microbial population, the formula was used

$$\text{Population (cfu/ml)} = \frac{colonycount}{volumeplated \times dilution\,plated}$$

Derivation of Model for Substrate Kinetics in an Anaerobic System

From the substrate kinetics, we look at the model for obtaining the specific rate of the domestic potato waste (substrates)

$$\text{Domestic Solid Waste (Sample)} + \text{Water} + \text{Microorganisms} \xrightarrow{K_1} \text{Product} + \text{Microorganisms}$$

That is;

$$[S] + [E] \xrightarrow{K_1} [P] + [\Sigma]$$

where S = the substrate (domestic potato solid waste) + water, E = Enzymes (microorganisms)
P = Product, Σ = Free Enzyme, K_1 = Rate of forward reaction

Considering the reaction equation

$$\frac{dS}{dt} = -\beta S \qquad (1a)$$

Where, S = substrate, ds = change in substrate concentration, dt = change in time, β = proportionality constant for the substrate (s)

By rearranging equation (1a), we have

$$\frac{dS}{S} = -\beta\ dt \qquad (1b)$$

Integrating equation (1b), we have

$$\int_{S_0}^{S_1} \frac{dS}{S} = -\beta \int_{t_0}^{t_1} dt \qquad (2)$$

$$\left[\ln S\right]_{S_0}^{S_1} = -\beta \left[t\right]_{t_0}^{t_1} \qquad (3)$$

Resolving equation (3), we have

$$\ln S_1 - \ln S_0 = -\beta \left(t_1 - t_0\right) \qquad (4a)$$

$$\ln S_1 - \ln S_0 = -\beta\ t_1 \qquad (4b)$$

$$\ln \frac{S_1}{S_0} = -\beta\ t_1 \qquad (5)$$

$$\beta = -\frac{1}{t_1} \ln \frac{S_1}{S_0} \qquad (6)$$

Recalling equation (1a) and applying Laplace transform, we have

$$\frac{dS}{dt} = -\beta S$$

$$\frac{dS}{dt} = SS^1{}_{(S)} - S^1{}_{(0)} \qquad (7a)$$

$-\beta S = -\beta S^{1}_{(S)}$ (7b)

Substituting equations (7a) and (7b) into equation (1a), gives

$SS^{1}_{(S)} - S^{1}_{(0)} = -\beta S^{1}_{(S)}$ (8)

By taking the boundary conditions,

at t=0, $S_{(0)} = S_0$ (9)

Putting equation (9) into equation (8), we have

$SS^{1}_{(S)} - S^{1}_{(0)} = -\beta S^{1}_{(0)}$ (10)

Rearranging equation (10), we have

$SS^{1}_{(S)} + \beta S^{1}_{(S)} = S^{1}_{(0)}$ (11)

From equation (11), we have

$S^{1}_{(S)} (S + \beta) = S^{1}_{(0)}$ (12)

Therefore, $S^{1}_{(S)} = \dfrac{S^{1}_{(0)}}{(S+\beta)}$ (13)

By taking the time domain of equation (1a), we have

$S_t = S_0 \ell^{-\beta t}$ (14)

From Michael's-Menten equation,

$$V = \frac{V_{Max}(S)}{K_S + (S)} = \frac{V_{Max}(H)}{K_H + (H)} \quad (15)$$

Then, combining equations (14) and (15), we have

$$S_t = \frac{(S_t)_{Max}(S)}{K_S + (S)} = \frac{(S_t)_{Max}(H)}{K_H + (H)} \quad (16a)$$

$$S_0 \ell^{-\beta t} = \frac{(S_0 \ell^{-\beta t})_{Max}(S)}{K_S + (S)} = \frac{(S_0 \ell^{-\beta t})_{Max}(H)}{K_H + (H)} \quad (16b)$$

$$S_0 \ell^{-\beta t} = \frac{(S_0 \ell^{-\beta t})_{Max}(S)}{K_S + (S)} \quad (16c)$$

Cross multiplying equation (16c), we have

$S_0 \ell^{-\beta t}\left[K_S + (S)\right] = (S_0 \ell^{-\beta t})_{Max}(S)$ (17)

Multiplying equation (17) by $\frac{1}{S_0 \ell^{-\beta t}}$

$$\frac{1}{S_0 \ell^{-\beta t}} \{S_0 \ell^{-\beta t}\left[K_S + (S)\right]\} = \frac{1}{S_0 \ell^{-\beta t}} \{(S_0 \ell^{-\beta t})_{Max}(S)\} \quad (18)$$

$$\left[K_S + (S)\right] = \frac{1}{S_0 \ell^{-\beta t}} \{(S_0 \ell^{-\beta t})_{Max}(S)\} \quad (19)$$

By making $\frac{1}{S_0 \ell^{-\beta t}}$ subject of the formula,

$$\frac{1}{S_0 \ell^{-\beta t}} = \frac{\left[K_S + (S)\right]}{\left(S_0 \ell^{-\beta t}\right)_{Max}(S)} \quad (20)$$

Now, comparing equation (20) with the Line-weaver Burk Plot

$$\frac{1}{V} = \frac{K_S}{V_{Max}(S)} + \frac{1}{V_{Max}} \quad \text{(Line-Weaver Burk Plot)}$$

$$\frac{1}{S_0 \ell^{-\beta t}} = \frac{K_S}{\left(S_0 \ell^{-\beta t}\right)_{Max}(S)} + \frac{(S)}{\left(S_0 \ell^{-\beta t}\right)_{Max}(S)} \quad (21)$$

$$\frac{1}{S_0 \ell^{-\beta t}} = \frac{K_S}{\left(S_0 \ell^{-\beta t}\right)_{Max}(S)} + \frac{1}{\left(S_0 \ell^{-\beta t}\right)_{Max}} \quad (22)$$

Thus, equation (22) is similar to the Line-Weaver Burk Plot

Mathematical Model Formulation

The Taylor's Variable Model for Domestic Solid Waste Degradation

From the Taylors Theorem. Stroud, (2006)

$$f(a + h) = f(a) + hf^1(a) + \frac{h^2}{2!} f^{11}(a) + \ldots\ldots\ldots \frac{h^n}{n!} f^n(a)$$

Truncating after second order,

$$f(a + h) = f(a) + hf^1(a) + \frac{h^2}{2!} f^{11}(a)$$

But considering the Taylor's Theorem in terms of x-coordinate only;

$$c((p+h),(w+k)) = c(p,w) + h\frac{\partial c}{\partial x^2} + \frac{1}{2}h^2\frac{\partial^2 c}{\partial x^2} \quad (23)$$

Considering the equation in terms of homogenous system

$$c((p+h),(w+k)) = 0$$

That is $$c(p,w) + h\frac{\partial c}{\partial x} + \frac{1}{2}h^2\frac{\partial^2 c}{\partial c^2} = c((p+h),(w+k)) \quad (24)$$

Let $$\alpha = \frac{\partial^2 c}{\partial x^2},\ \beta = \frac{\partial c}{\partial x},\ \propto = c(p,w) = c(p) = c(w) \quad (25)$$

For P^H,

$$P^H = \frac{1}{2}\alpha h^2 + \beta h + \propto \quad (26)$$

$$y = \frac{1}{2}\alpha h^2 + \beta h + \propto \quad (27)$$

And for weight loss Concentration (M)

$$m = \frac{1}{2}\alpha k^2 + \beta k + \propto \quad (28)$$

$$x = \frac{1}{2}\alpha k^2 + \beta k + \propto \quad (29)$$

3. RESULTS AND DISCUSSION

The results obtained from the research are presented in Figure as shown in this research work.

Figure 1 demonstrates the relationship between concentration (weight loss) of potato waste and time. From the figure, it is shown that the concentration of potato waste decreases with increase in time due to the influence of microorganisms in the bioreactor system. Similarly, the variation in concentration of the potato can be attributed to variation in time. A sudden decrease in the degradation of potato was observed from > 0 to < 4 days with a lag phase which can be attributed to variation in P^H value acting as an inhibitor in the batch reactor. Then after, an exponential phase was noticed as a result of the microbial build-up.

Figure 2 shows the relationship between acidic value (P^H) of the fish gill and time with the microbial activities as an influencing factor in the anaerobic bio reactor system. From the figure, it is noted that a slight decrease in P^H value occurred from > 0 to < 22 days with a lag phase. Similarly, the P^H suddenly increased from > 22 to < 24 with an exponential phase and then after, was static from > 24 to < 30 days with a stationary phase indicating inhibition in the microbial growth inside the bioreactor. From the figure, the variation in P^H of fish gill can be attributed to variation in time.

Figure 3 shows the relationship between $\frac{1}{V_{PO}^{0-30}}$ (reciprocal of the specific rate of degradation of potato waste) and $\frac{1}{S_{PO}^{0-30}}$ (reciprocal of the substrate) using Michael Mentene Model. From the figure, it shows that the potato degradation obeyed the Line

Weaver Burk Plot Model since the interception of the gradient line is on the vertical axis of the graph. The points indicate the increase and decrease in reciprocals of the specific rate and substrate values respectively. From the line Weaver Burk plot, Michael Menten model was established with an intercept given as 0.2858. The intercept upon mathematical formulation, gave rise to the maximum specific rate of 3.5 g/l/day and Michael Menten dissociation constant, $K_{l.}$

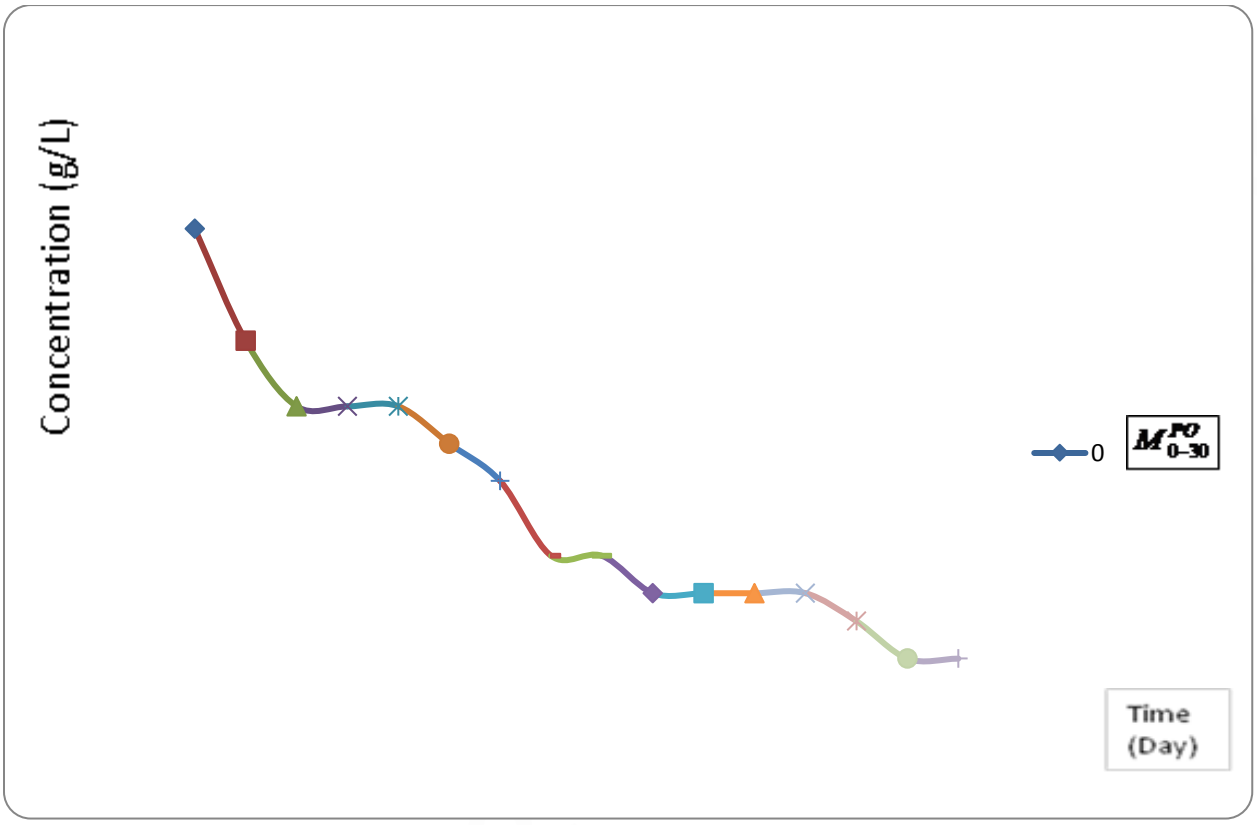

Figure 1 Graph of Potato Waste Degradation Concentration versus Time

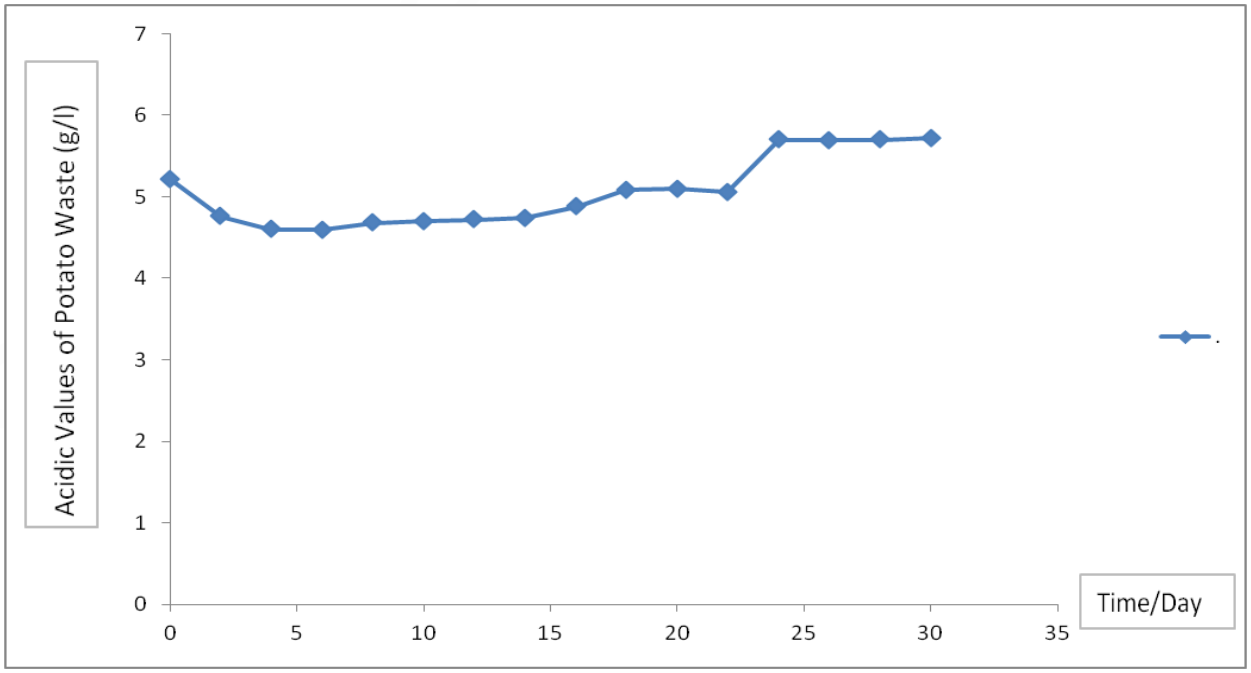

Figure 2 Graph of Acidity (P^{H}) of Potato Waste Degradation versus Time.

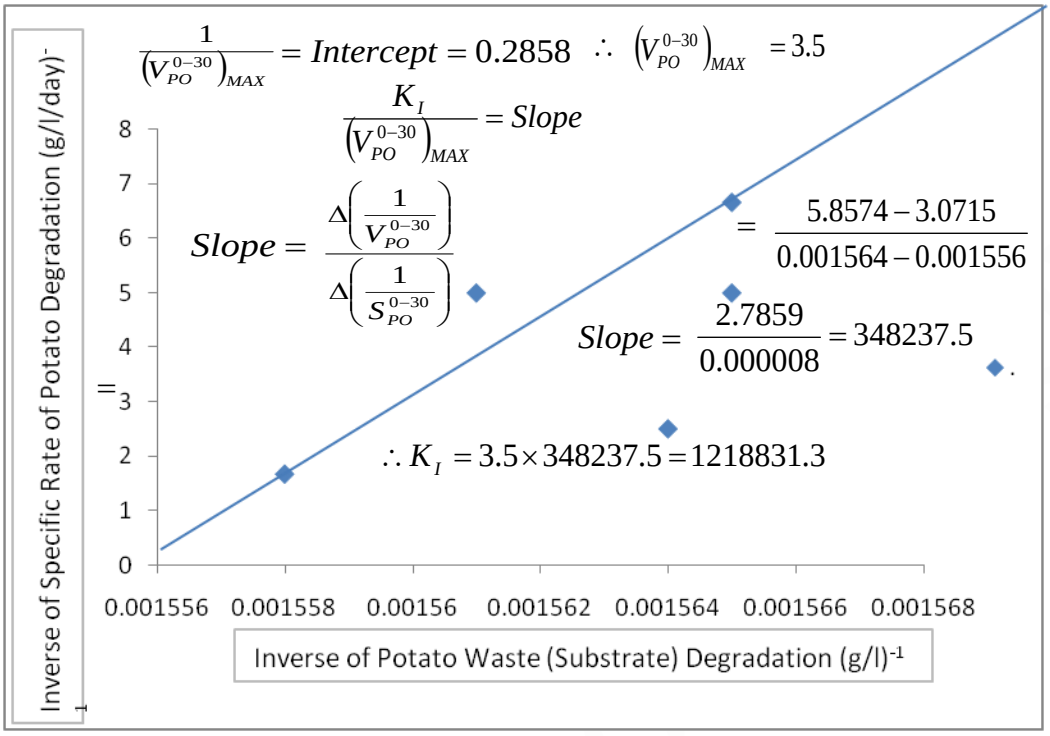

Figure 3 Graph of Line Weaver Burk Plot for Potato Waste Using Michael Mentene Model

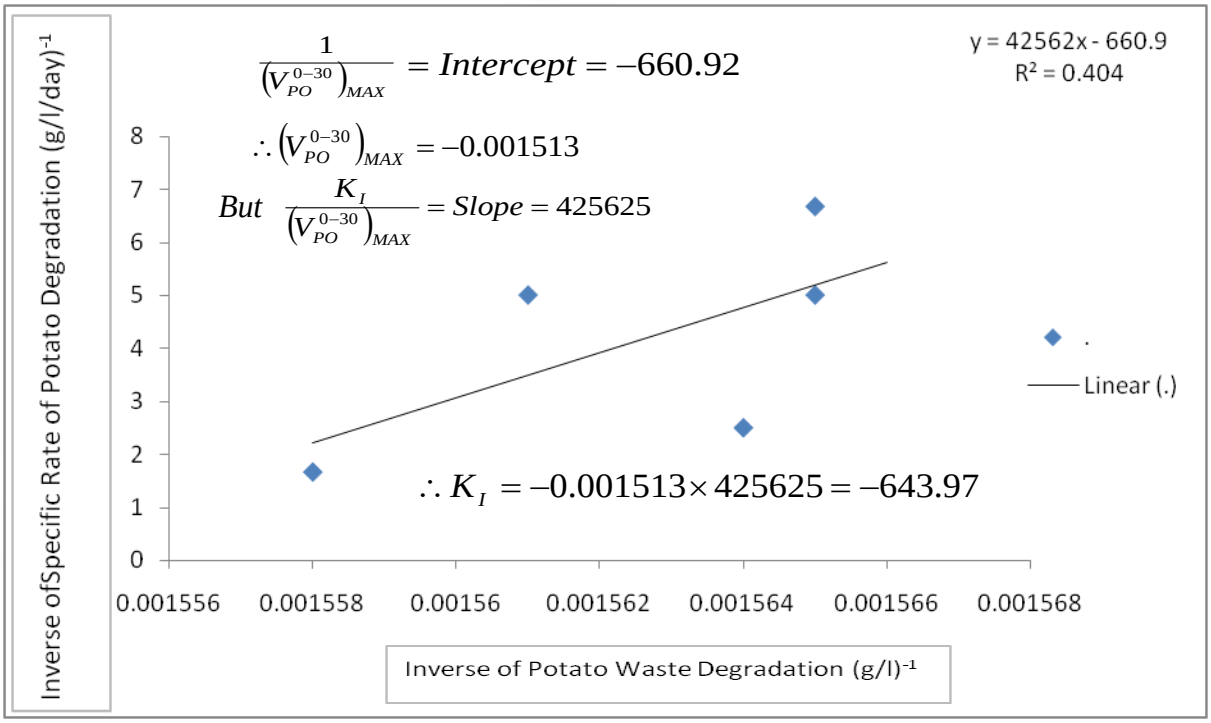

Figure 4 Graph of Line Weaver Burk Plot for Potato Waste in Linear

Form Figure 4 explains the relationship between $\frac{1}{V_{PO}^{0-30}}$ (reciprocal of the specific rate of degradation of potato waste) and $\frac{1}{S_{PO}^{0-30}}$ (reciprocal of the substrate) in linear form. The points given in the figure shows an increase and decrease in reciprocal of the specific rate of degradation of the potato waste and reciprocal of the substrate in the bioreactor system. The linear equation of the curve is established as y = 425625x – 660.92. This indicates an intercept value of -660.92 and slope as 425625. The intercept is equal to while the slope is equal to $\frac{K_I}{\left(V_{PO}^{0-30}\right)_{MAX}}$

4. CONCLUSION

The domestic potato solid waste degradation was observed resulting to changes in concentrations and changes in P^H values as a result of time and microbial influence in the bioreactor system. The extent of concentration and change in P^H of the sample was observed as functions of time. The acidity of the potato waste was noted initially as having the high acidic value with P^H range of 4.59. Furthermore, the microbiological analysis conducted shows that potato waste has high fungi population than bacteria population. This observed phenomenon is attributed to the nutritional content of the sample which proves that fungi favors substrates with high carbohydrate content as the bacteria favors the substrates with high protein content.

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