B09: Mathematical Modelling of Enzyme Hydrolysis and Fermentation of Banana Trunk Biomass for Optimum Ethanol Production

Evans Patience Ogheneofejiro[1*], Jiya Mohammed[2] Nyor Ngutor[2] and Yisa Jonathan[3]

[1*] Department of Mathematics, Federal Polytechnic Bida.
[2, 3]Department of Mathematics, Federal University of Technology Minna.
[4] Department of Chemistry, Federal University of Technology Minna.
[1*]patevansjj@gmail.com[1]

Abstract

The rising demand for ethanol consumption calls for optimal production model since it has been found to be an alternative source of sustainable energy and in high demand in industries. This work aims at varying the Kinetic variables in the production of ethanol from enzyme hydrolyzed and fermented Banana Trunk Biomass. The methodology of consecutive reaction in which the reaction rate (K_1, K_2 and K_3) is varied at each stage of production to see the effect on residue, glucose and ethanol yield respectively. The results shows that increase in the rate of pretreatment (K_1) increases residue, glucose and ethanol yields, increasing the rate of hydrolyses (K_2) reduces the residue and increases glucose and ethanol yield whereas increase in fermentation rate (K_3) decreases glucose yield and increases the yield of ethanol.

Keywords: Mathematical Modeling, Kinetic, Banana Trunk Biomass, Ethanol, Hydrolysis, Optimum.

1. Introduction

Ethanol is a liquid fuel that can be produced from the hydrolysis of starch and fermentation of glucose. It is a volatile, colorless, and flammable chemical (Graeme, 2010). Ethanol can be produced from coarse grain such as corn and millet; sugarcane, cassava, biomass containing cellulose such as agricultural waste, municipal waste, woody materials, forest residues, by–product of organic materials, herbaceous material (Egwim *et a*l., 2015). Lignocellulosic materials such as agricultural residues (wheat straw, corncob and paddy straw); Energy crops (switch grass and fast-grow trees) and forest resources have been recognized as renewable for industrial applications to produce ethanol and other biofuels (Chin, *et. al*., 2011)

Banana Trunk Biomass can be used as a raw material for ethanol production because it contains sugar with high level of glucose or precursors to glucose (Badger, 2002; Egwim *et a*l., 2015). Historically, fermentation products were mainly food products, but in recent years an increased interest has been observed in the production of bulk chemicals (ethanol and other solvents), specialty chemicals (Pharmaceuticals, industrial enzymes), biofuels and food additives (flavor modifiers) Fermentation processes are also used in agriculture.

According to Nyor *et al.*, (2018), banana trunk biomass is a renewable polymer abundant in nature particularly in Nigeria; as Nigeria is ranked among the highest producers of banana in West Africa. The biomass is often wasted after harvesting the Banana fruit. Currently there are trends in hydrolyzing banana trunk polymers, using enzyme processes to produce fermentable sugars and the fermentable sugar is further converted into ethanol. This is a cheaper way of producing ethanol and it can be used as renewable fuel.

The production of ethanol can be control and optimize when we understand the dynamic and behaviour of ethanol production (Paz and Cardona, 2011). Mathematical models give us adequate Knowledge of real life phenomenon. It also gives rise to variables manipulation. Kinetic modelling has been regarded as an important step in developing fermentation process, since models help in both process control and research efforts, which is most effective in reducing process costs and increasing product quality (Olaoye and Kolawole 2013)..

This work is aimed at checking the effect of varying the kinetic variables and observing the effect on the concentration of the biomass residue, glucose yield and ethanol t from pretreated Banana Trunk.

2. Literature Review

The high amount of cellulose and lignocellulosic plant material found in banana truck is wasted yearly (Soffner, 2001). In the recent times there is a high demand for ethanol which make it necessary for the production of ethanol from less expensive feedstock such as lignocellulose materials (Taherzadeh and Karimi, 2007).

Olaoye and Kolawole (2013), used logistic model to illustrate the kinetics of biomass conversion with respect to time. They also demonstrated that the modified Gomperta model can be used to test the kinetics of ethanol production at a steady temperature. Literature supports that the utilization of mathematical model will contribute to a better understanding of effects of various factors, affecting production of ethanol.

Farah *et al* (2011), Used computer simulation of four different kinetic models They observed that Teisser model gave marginally better fit than Monod, Contois, Modified Monod models tested as it obtained the highest correlation coefficient of 0.96299..

3. Mathematical Formulation

In the production of ethanol from pretreated banana trunk biomass a pattern of a consecutive reaction was considered. (Martinopa, 1987; Yu, 2014 and Olaoye and Kolawole 2013).

The ODE that describe the above process is given by

$$\frac{dB}{dt} = -k_1 B \qquad B(0) = B_0 \tag{3,1}$$

$$\frac{dR}{dt} = -k_1 B - k_2 R, \qquad R(0) = 0 \tag{3.2}$$

$$\frac{dG}{dt} = k_2 R - k_3 G, \qquad G(0) = 0 \tag{3.3}$$

$$\frac{dE}{dt} = k_3 G, \qquad E(0) = 0 \tag{3.4}$$

Where,

B = Banana trunk biomass,

R = Residue

G = Glucose

E = Ethanol

k_1, k_2 *and* k_3 *are the rate of reaction*

From equation (3.1), the rate of change of biomass with time is given by,

$$B(t) = B_0 e^{-k_1 t} \tag{3.4}$$

From equation (3.2), the concentration of residue at time t, becomes

$$\frac{dR}{dt} + k_2 R = k_1 B_0 e^{-k_1 t} \tag{3.5}$$

Using integrating factor method, we have,

$$R(t) = e^{-k_2 t} \int_0^t k_1 C_{B0} e^{(k_2 - k_1)x} dx + C_2 e^{-k_2 t} \tag{3.6}$$

That is,

$$R(t) = \frac{k_1 B_0}{(k_2 - k_1)} \left(e^{-k_1 t} - e^{-k_2 t} \right) + C_2 e^{-k_2 t} \tag{3.7}$$

$$R(0) = C_2 = 0 \Rightarrow C_2 = 0 \tag{3.8}$$

Therefore,

$$R(t) = \frac{k_1 B_0}{(k_2 - k_1)} \left(e^{-k_1 t} - e^{-k_2 t} \right), \ \forall \ k_1 \neq k_2 \tag{3.9}$$

From equation (3.3) the rate of change of glucose with time becomes

$$\frac{dG}{dt} + k_3 G = \frac{k_1 k_2 B_0}{(k_2 - k_1)} \left(e^{-k_1 t} - e^{-k_2 t} \right) \tag{3.10}$$

Using integrating factor method, we have,

$$G(t)=e^{-k_3 t}\int_0^t \frac{k_1 k_2 B_0}{(k_2-k_1)}\left(e^{(k_3-k_1)x}-e^{(k_3-k_2)x}\right)dx + C_3 e^{-k_3 t} \tag{3.11}$$

$$G(t)=e^{-k_3 t}\frac{k_1 k_2 B_0}{(k_2-k_1)}\left(\left[\frac{e^{(k_3-k_1)x}}{((k_3-k_1))}\right]_0^t-\left[\frac{e^{((k_3-k_2))x}}{((k_3-k_2))}\right]_0^t\right)+C_3 e^{-k_3 t} \tag{3,12}$$

$$G(t)=\frac{k_1 k_2 B_0}{(k_2-k_1)}\left(\frac{\left(e^{-k_1 t}-e^{-k_3 t}\right)}{(k_3-k_1)}-\frac{\left(e^{-k_2 t}-e^{-k_3 t}\right)}{(k_3-k_3)}\right)+C_3 e^{-k_3 t} \tag{3.13}$$

$$G(0)=C_3=0 \Rightarrow C_3=0 \tag{3.14}$$

Therefore,

$$G(t)=\frac{k_1 k_2 B_0}{(k_2-k_1)}\left(\frac{\left(e^{-k_1 t}-e^{-k_3 t}\right)}{(k_3-k_1)}-\frac{\left(e^{-k_2 t}-e^{-k_3 t}\right)}{(k_3-k_2)}\right), \quad \forall\, k_1 \neq k_2 \neq k_3 \tag{3.15}$$

From (3.4), the rate of production of ethanol with time becomes,

Integrating with respect to time t, we have,

$$E(t)=\frac{k_1 k_2 k_3 B_0}{(k_2-k_1)}\left(\frac{e^{-k_3 t}}{k_3(k_3-k_1)}-\frac{e^{-k_1 t}}{k_1(k_3-k_1)}+\frac{e^{-k_2 t}}{k_2(k_3-k_2)}-\frac{e^{-k_3 t}}{k_3(k_3-k_2)}\right)+C_4 \tag{3.17}$$

At time t=0 E(0)=0

$$\Rightarrow C_4=\frac{k_1 k_2 k_3 B_0}{(k_2-k_1)}\left(\frac{1}{k_1(k_3-k_1)}-\frac{1}{k_3(k_3-k_1)}+\frac{1}{k_3(k_3-k_2)}-\frac{1}{k_2(k_3-k_2)}\right) \tag{3.19}$$

Therefore,

$$E(t)=\frac{k_1 k_2 k_3 B_0}{(k_2-k_1)}\left(\frac{\left(e^{-k_3 t}-1\right)}{k_3(k_3-k_1)}-\frac{\left(e^{-k_1 t}-1\right)}{k_1(k_3-k_1)}+\frac{\left(e^{-k_2 t}-1\right)}{k_2(k_3-k_2)}-\frac{\left(e^{-k_3 t}-1\right)}{k_3(k_3-k_2)}\right), \forall k_1 \neq k_2 \neq k_3 \qquad (3.20)$$

4. Results and Discussion

The result of the effect of rate of reaction on the yield of Residue, glucose and ethanol at different stages is shown in figure 3.1 to 3.9

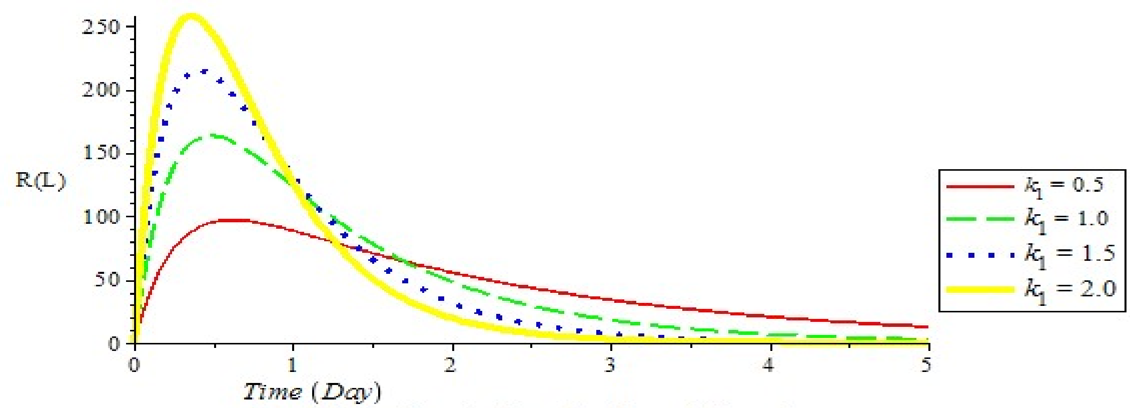

Figure 3.1 : Residue Time Profile at different k_1.
($k_2 = 3.8.$ $k_3 = 2.2$)

The result in Figure 3.1 illustrates the effect of increase in K_1 on the pretreatment, where the optimum Residue is 250 L at day one. This implies that increase K_1 increases the residue.

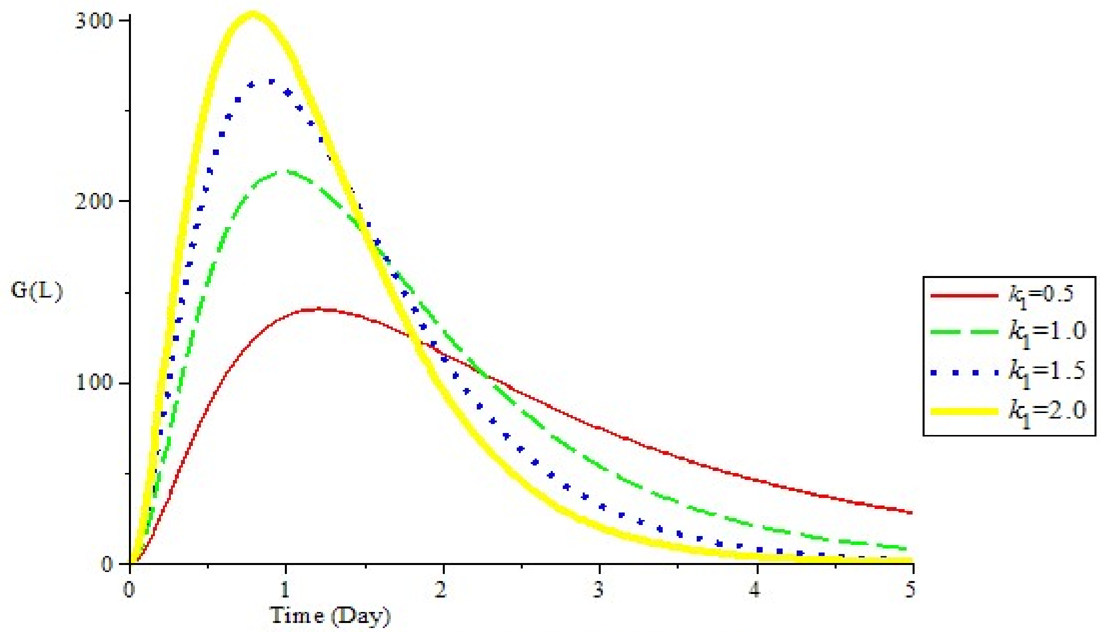

Figure3.2: Glucose Time Profile at different k_1.
(k_3=3.8, k_3=2.2)

The result in Figure 3.2 depicts the effect of K_1 on the hydrolysis process, where the optimum Glucose yield is 300 L at day one when K_1=2.0. This implies that increase K_1 increases the glucose yield..

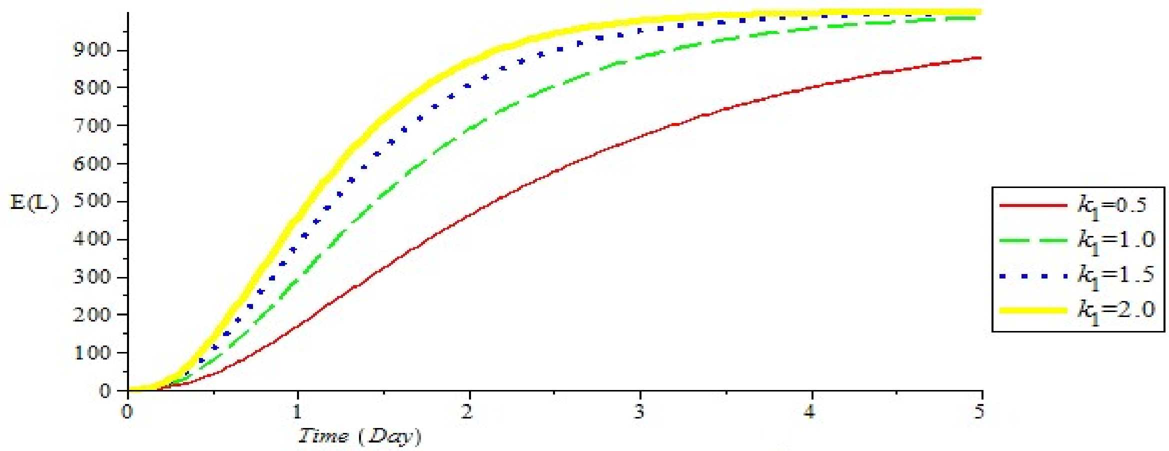

Figure 3.3 : Ethanol Time Profile at different k_1.
$(k_2 = 3.8, k_3 = 2.2)$

The result in Figure 3.3 shows the effect of K_1 on the fermentation process, where the optimum Ethanol yield is 950 L at day two when K_1=2.0. This implies that increase K_1 increases the Ethanol yield..

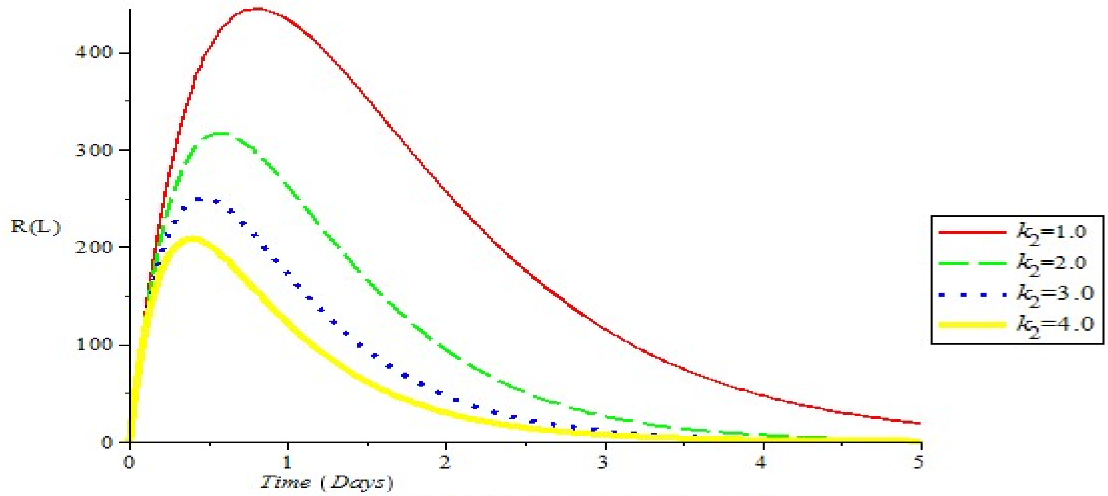

Figure 3.4 : Residue Time Profilewith different k_2.
$(k_1 = 1.5, k_3 = 2.2)$

The result in Figure 3.4 shows the effect of K_2 on the pretreatment process, where the optimum is at day one with a residues yield of 450 L when K_2=1.0. This implies that decrease K_2 increases the residue yield..

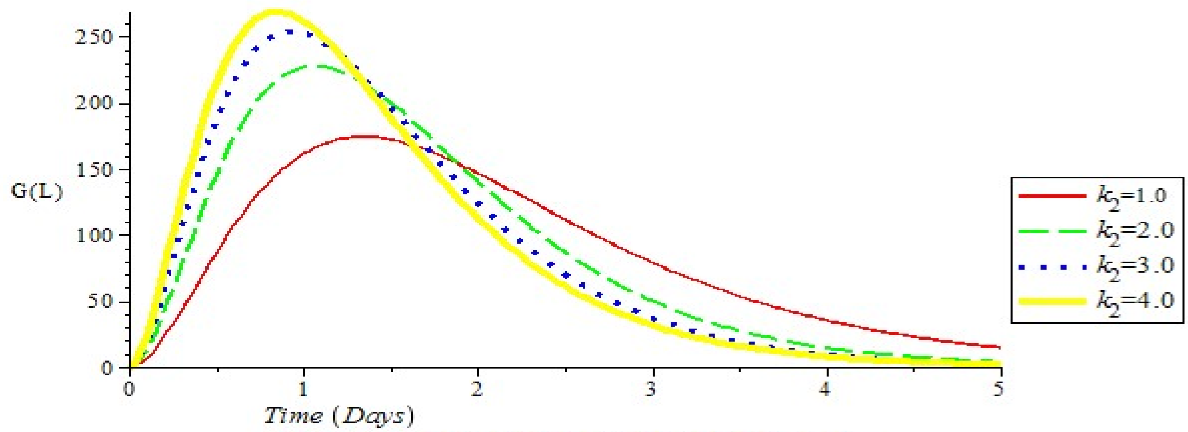

Figure 3.5 : Glucose Time Profilewith different k_2.
$(k_1 = 1.5, k_3 = 2.2)$

The result in Figure 3.5 illustrates the effect of K_2 on the hydrolysis process, where the optimum Glucose yield is 290 L at day one when K_2=4.0. This implies that increase K_2 increases the Glucose yield..

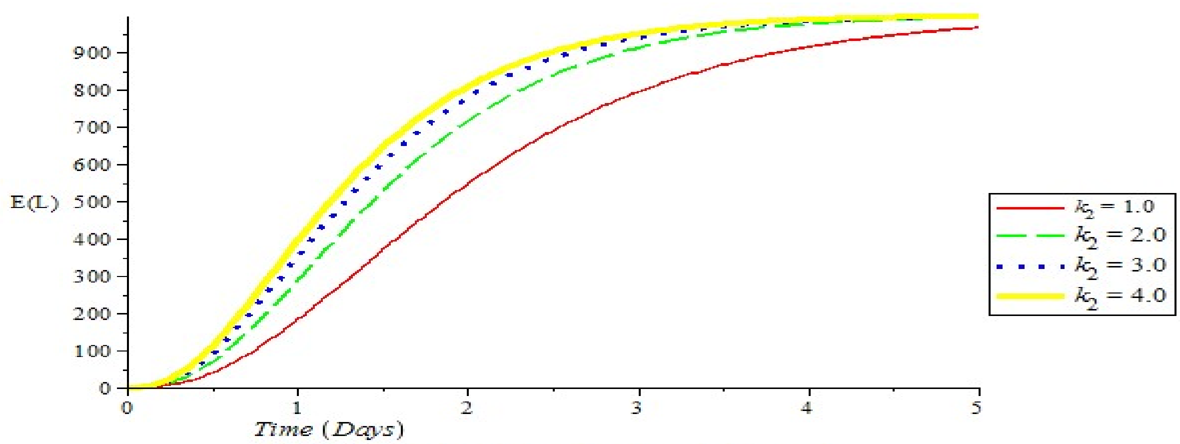

Figure 3.6 : Ethanol Time Profilewith different k_2.
$(k_1 = 1.5, k_3 = 2.2)$

The result in Figure 3.6 depicts the effect of K_2 on the fermentation process, where the optimum Ethanol yield is 960 L at day two when K_2=4.0. This implies that increase K_2 increases the Ethanol yield..

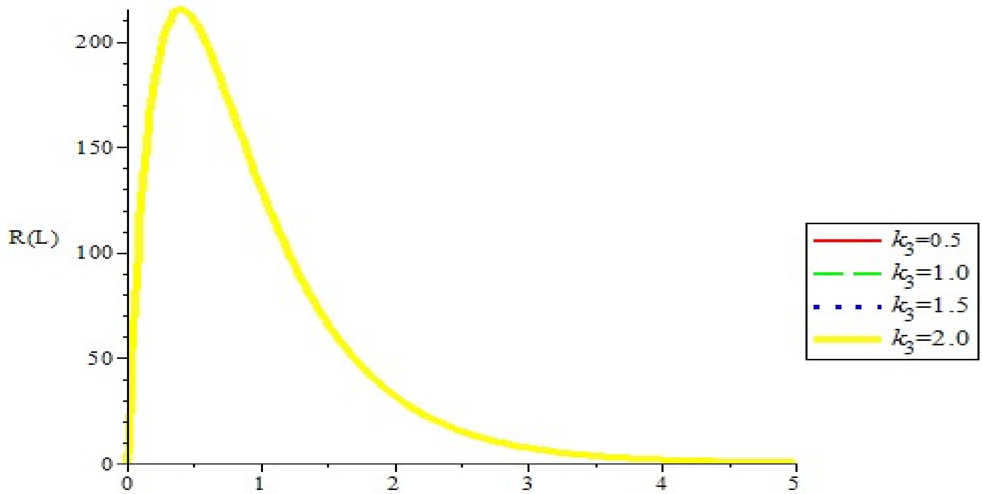

Figure 3.7 : Residue Time Profile at different k_3.
$(k_3 = 1.5, k_3 = 3.8)$

The result in Figure 3.7 depicts the effect of K_3 on the pretreatment process, where the optimum Residue yield is 230 L at half a day when K_3 = 2.0. This implies that at low K_3 the residues are all being converted to glucose.

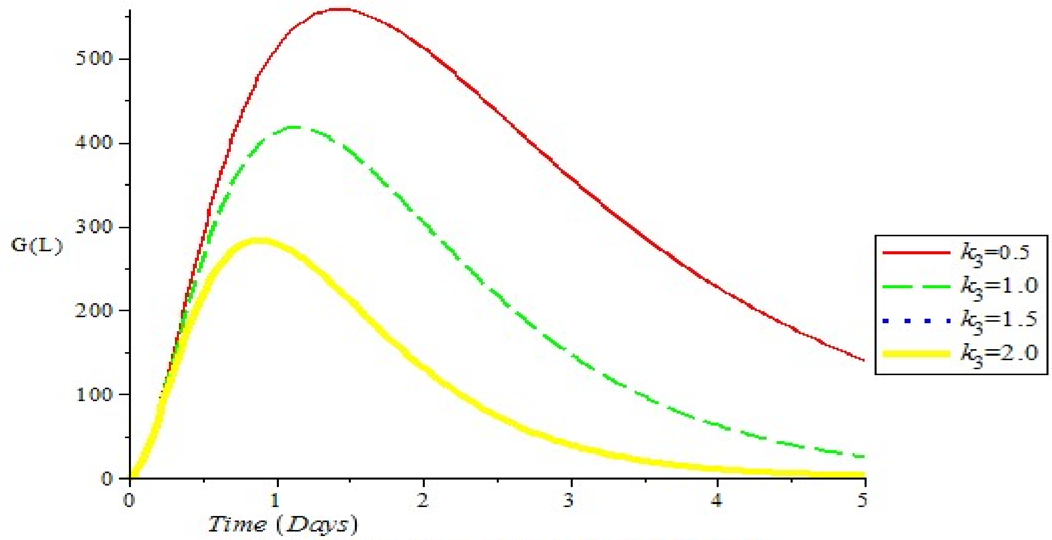

Figure 3.8 : Glucose Time Profile at different k_3.
$(k_1 = 1.5, k_2 = 3.8)$

The result in Figure 3.8 illustrates the effect of K_3 on the hydrolysis process, where the optimum Ethanol yield is 520 L at day two when K_3=0.5. This implies that decrease K_3 increases the Ethanol yield..

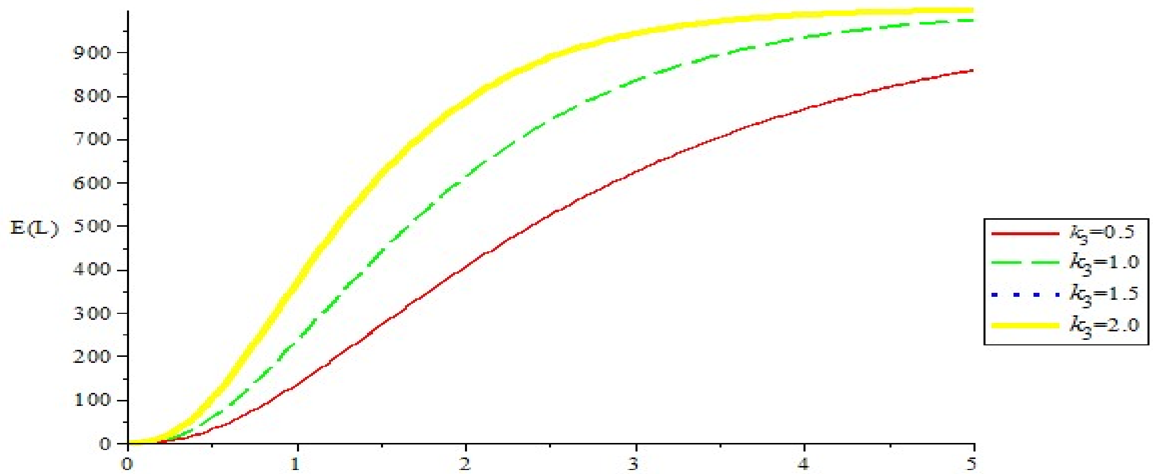

Figure 3.9 : Ethanol Time Profile at different k_3.
$(k_1 = 1.5, k_2 = 3.8)$

The result in Figure 3.9 depicts the effect of K_3 on the fermentation process, where the optimum Ethanol yield is 980 L at day three when K_3=4.0. This implies that increase K_3 increases the Ethanol yield.

5. Conclusion

The result concludes that increase in the rate of pretreatment (K_1, K_2 and K_3), hydrolyses and fermentation increases the yield of ethanol but high hydrolysis rate reduces the residue this may be due to the use of more of the residue to produce glucose during hydrolysis, While increase in fermentation rate decreases glucose yield this may be due to the use of more of the glucose to produce ethanol during fermentation.

References

Badger, P. C (2002) Ethanol from Cellulose a General Review. ASHS Press, Alexandra. Pp 17 – 21.

Chin K. L, H'ng PS, Wong L J, Tey B. T and Paridah M. T. (2011) Production of Glucose from Oil Palm Trunk and Sawdust of Rubberwood and Mixed Hardwood. *Applied Energy*. 88(42). Pp22–28.

Egwim E.C, Shittu K. O, & Komolafe D. (2015) Microwave – Alkaline Assisted Pretreatment of Banana Trunk for Bioethanol Production. *Journal of energy and Power Engineering.* Vol. 9: Pp 705 – 713. doi: 10.17265/1934-8975/2015.08.003

Farah Ahmad, Ahmad Tariq Jameel, Mohd Hider Kamarudin and Maizirwan Mel. (2011) Study of Growth Kinetic and Modeling of Ethanol Production by *Saccharomyces cerevisae*. *African Journal of Biotechnology.* Vol. 16(81), pp. 18842 – 18846.

Graeme, M. W. (2010). *Bioethanol: Science and Technology of Fuel Alcohol.* Copenhagen: Graeme M.Walker & Ventus Publishing Aps, 49-52.

Nyor N., Evans P. O., Jiya M. and Yisa J. (2018). A Lagrange Revenue Model For Ethanol Production from Biomass. Transactions of the Nigerian Association of Mathematical Physics. Vol 4, Pp 193-204

Par Astudila I. C And Cardona Alzate C. A (2011). Importance of Stability Study of Continuous Systems for Ethanol Production. *Journal. Bioethanol* 151: 43 – 55.

Olaoye O. S. and Kolawole O. S. (2013). Modeling of the Kinetics of Ethanol Fermentation from Glucose Biomass in Batch Culture with a Non – Structural Model. *International Journal of Engineering Reseach and application* (IJERA) Vol. 3. Issue 4. Pp 562 – 565.

Soffner, M. L. A. O. (2001). "Pulp Production from Banana Stem." Master thesis, University of Sao Paulo.

Taherzadeh, M. J., & Karimi, K. (2007). Acid-Based Hydrolysis Processes for Ethanol from Lignocellulosic Materials: A Review. *BioResources*, 2, 472-499.