VOL. 17, NO. 23, DECEMBER 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

MODELLING AND CONTROL OF A BIO-ETHYLENE PRODUCTION PROCESS

Florence Ilueh-Ochuweh Bullem, Idowu Iyabo Olateju and Abdulwahab G. I. W. A.
Department of Chemical and Petroleum Engineering, Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria
E-Mail: bullem.florence@abuad.edu.ng

ABSTRACT

Ethylene is one of the most consumed products in the world, as it has many uses such as the production of nylon from its polymeric compound, the production of vinyl chloride, which is polymerized to polyvinyl chloride for the production of plastics, the production of ethylene oxide, used as a ripening agent for fruits, etc. The conventional method adopted in the production of ethylene is by steam cracking of naphtha at high temperatures. Naphtha is a hydrocarbon, so when cracked, it releases harmful carbon dioxide (CO_2) into the atmosphere, and this brought about looking for alternative methods of producing ethylene. As discovered, ethylene can be produced by catalytic dehydration of ethanol, but the main limitation of this process is that the purity of ethylene produced by this approach may not be up to the desired polymer grade of 99.97%. As such, this work has been carried out to model, with the aid of Aspen Plus, and develop control techniques that would enable the process to meet up with the desired output maximum purity from the distillation column (100% ethylene at the top product of the distillation column). In line with that, P-only, PI, and PID controllers tuned with the Tyreus-Luyben technique, Zeiger-Nichols method, and a modified Tyreus-Luyben approach have been used for the control of this process. It was discovered that the PID controller tuned with the modified Tyreus-Luyben parameter had the lowest Integral Absolute Error (IAE) of 1.474 and Integral Time Absolute Error (ITAE) of 4.767 and, hence, it was found out that it could be adopted for proper control of this process, although limited to small upsets caused by disturbances in the system. It is, therefore, recommended that the PID control system developed should be applied on a physical set-up plant to study its real effect.

Keywords: bioethanol, bio-ethylene, aspen Plus, process control, open-loop, closed-loop.

NOMENCLATURE

FOPTD	First Order Plus Time Delay
IAE	Integral Absolute Error
ISE	Integral Squared Error
ITAE	Integral Time Absolute Error
K_P	Process static gain
MATLAB	MATrix LABoratory
MPC	Model Predictive Controller
PID	Proportional Integral Derivative
PVC	Polyvinyl chloride
τ_d	Delay time(sec)
τ_p	Process time constant(sec)

1. INTRODUCTION

The twentieth century has been the "oil" era, where fossil-derived products, such as fuels, commodity chemicals, and consumer goods were derived from the refining industry. Nevertheless, the world we know today questions the sustainability of those non-renewable resources for future generations. The renewable-based chemicals and products are slowly emerging and making their steps into the market and our economy is drifting gradually to a bio-driven economy as it was petroleum-driven in the past. One of those products is bio-ethylene (Seader, 2010).

Ethylene is currently the most consumed intermediate product in the world, as it is used in the production of polyvinyl chloride (PVC) and nylon when it undergoes polymerization (Wu and Wu, 2017).

As of 2014, the CO_2 emissions into the atmosphere was 85.70MT CO_2/yr and by 2019, it rose to 100.2270MT CO_2/yr which is about a 14% increase in 5 years. The higher the amount of this GHG going into the atmosphere, the greater the risk of climate change and global warming. The amount of CO_2 in the atmosphere has increased from about 280 ppm (at the pre-industrial level) to 385 ppm and is constantly increasing at about 2 ppm/year. The recent climate safety report finds that we need to return greenhouse gases to about 300ppm, which is close to that of the pre-industrial level and it was recommended that it would be necessary to reduce atmospheric CO_2 concentrations to 350ppm at most to be able to maintain the global warming below 2℃ (INFORSE, 2008). About 25% of CO_2 in the atmosphere is absorbed by plants to carry out photosynthesis and 30% by the ocean surface. By planting more trees and plants to obtain biomass, more CO_2 will be absorbed by the plants and this process eliminates the risk of global warming in the years to come. All these proposals can be achieved by

utilizing ethylene obtained from bioresources (Bi *et al.*, 2009).

Morschbacker (2017) reviewed bioethanol-based ethylene as raw material to produce bioplastics, e.g., polyethylene, with a focus on the aspects relative to ethanol manufacture in Brazil, using sugarcane as feedstock. He concluded that ethanol conversion and the reaction selectivity have a direct impact on the yield, and consequently, on the costs of the process. He also discussed that bioethanol-based polyethylene can be an alternative to plastics that have come to the end of their life. It can be recycled mechanically or by incineration since it releases a non-fossil carbon dioxide that will be equivalent to the quantity absorbed by the sugarcane crop at the beginning of the cycle. Zhang *et al.* (2008) also reviewed the process of ethanol to ethylene, and mainly focused on the reactor design, the reaction mechanism, and the catalyst. They concluded that a fluidized bed reactor with an efficient and stable catalyst and a deep understanding of the reaction mechanism would be the focus of future research. This will promote the development of the process and provide strong support for market competition (Giwa *et al.*, 2018). The application of PI and PID forms of a control system has been carried out by Giwa (2016).

Bio-ethylene is produced by the catalytic dehydration of bioethanol rather than the cracking of hydrocarbons, and it requires less energy to operate and emits a lower amount of CO_2 (Bullem, 2021).

This process may not produce as much ethylene as required for human use because of the availability of raw materials (crude oil) for the conventional process, but with more research, economic analysis, and process optimization, the world at large will make a shift to using the bioprocessing technique and reduce the effect of the greenhouse gases to the environment.

One challenge discovered to be facing bio-ethylene production is in the area of the control of the process. Therefore, this work is aimed at bridging the gap and contributing more (control objectives to be followed by the bio-ethylene process) to the already existing bank of knowledge.

2. METHODOLOGY

2.1 Process Model Development and Steady State Simulation

The ethanol dehydration process catalysed by ZSM-5catalyst involves two reaction mechanisms starting with ethanol being dehydrated to produce diethyl ether and diethyl ether being converted to ethylene as described in Equations (1) and (2).

$$2C_2H_5OH \leftrightarrow C_4H_{10}O + H_2O \quad (1)$$

$$C_4H_{10}O \rightarrow 2C_2H_4 + H_2O \quad (2)$$

The process model was developed and simulated using Aspen Plus (Aspen, 2019) process modeller via the following steps:

a) **Component selection:** The chemical components, which were ethanol, ethylene (ethene), and water, involved in the process were added to the system from the Aspen plus database.
b) **Method:** Peng-Robinson equation of state was chosen as the base method (Figure-1).

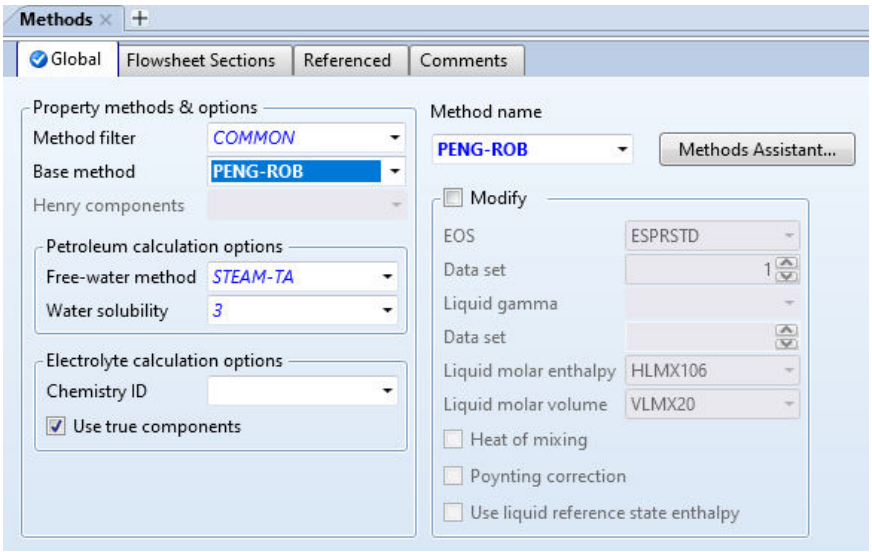

Figure-1. Aspen Plus showing the selected method.

c) **Flowsheet Development:** This process model was developed on the Aspen Plus simulation environment through the following stages:

- **Stage 1:** A heater from the equipment palette was added to the environment and one material stream from the palette was connected to the pump to increase the temperature of the feed. The inlet stream was named FEED and the outlet was named HEATPROD.

- **Stage 2:** The outlet from the heater was connected to a stoichiometric reactor that was picked from the equipment palette. In this reactor, two reactions were occurring in series, ethanol forming diethyl ether and water and diethyl ether forming ethylene and water. The reactor product was called RPROD.
- **Stage 4:** The reactor product was connected to a cooler to lower the temperature. The outlet of the cooler was called COOLPROD.
- **Stage 5:** The cooler outlet was connected to the distillation column. The operating conditions of the column were specified, and the outlet streams were named TOPPROD and BTTMPROD. See Figure-2.

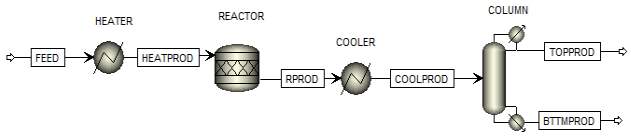

Figure-2. The developed flowsheet of the process.

d) Feed stream specification: The conditions of the feed stream were specified. The specified parameters for the feed stream were as shown in Table-1.

Table-1. Operating parameters for feed stream.

Feed stream	Ethanol
Temperature (℃)	25
Pressure (bar)	1
Total flow rate (kmol/hr)	1
Mole fraction	1

e) Reaction specification: The reaction parameters for the catalytic dehydration of ethanol were specified as given in Table-2.

Table-2. General reaction data.

Parameters	Value
Temperature (℃)	400
Pressure (bar)	6
Fractional conversion of ethanol	0.9

f) Distillation column specification: The operating parameters for the distillation column were as given in Table-3.

Table-3. Operating parameters for the distillation column.

Parameters	Value
Number of stages	11
Condenser type	Total
Fractional conversion of ethanol	0.9
Reflux ratio	25
Distillate to feed ratio	0.5
Feed stage	6
Condenser pressure (kPa)	90

2.2 Sensitivity Analysis

Sensitivity analysis was carried out by varying the distillate-to-feed ratio and noting the effect on the composition of ethylene at the top product of the distillation column. The relationship between the process variables was investigated by considering the plots generated from the data obtained.

2.3 Process Transfer Function Generation

The process transfer function model used in this work was generated by developing the transfer function relations between ethylene mole fraction (output variable) and distillate-to-feed ratio (input variable) using the data generated from the Aspen Plus simulation.

The process model transfer function formulation was done via a MATLAB code from a script (Appendix A) file using MATLAB (MathWorks, 2018) software. By running the script, the sensitivity analysis data of the simulated process was called from the Microsoft Excel spreadsheet and exported to the System Identification Toolbox Interface on the MATLAB program.

On the System Identification Toolbox Interface, a transfer function model of the form shown the Equation 3 was developed.

$$G_p(s) = \frac{K_p e^{-\tau_d s}}{\tau_p s + 1} \quad (3)$$

2.4 Simulink Modelling and Open-Loop Simulation of the Process

The transfer function obtained in Equation 3 was modelled in a Simulink environment embedded in the MATLAB software by combining appropriate blocks. The developed Simulink model for the open-loop system is shown in Figure-3. The open-loop dynamics of the process were studied by applying a unit step change to the process manipulated and the disturbance variable. The Simulink open-loop model was run using codes written in a MATLAB script file (Appendix B).

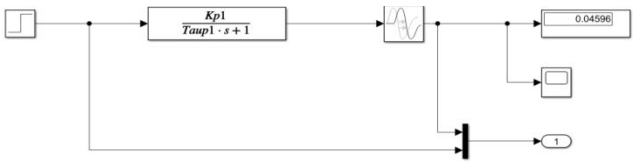

Figure-3. Open-loop simulink model of the process.

2.5 Closed-Loop Simulation and Control of the Process

The closed-loop simulation was achieved by modifying the open-loop simulation as shown in Figure-4. A PID controller and a summing point were added to

calculate the error and adjust the controller accordingly. The PID controller was tuned manually, with Tyreus-Luyben, Tyreus-Luyben fine-tuned and with Zieger-Nichols Tuning parameters (Appendices C - H) to select the best parameters for controlling the process.

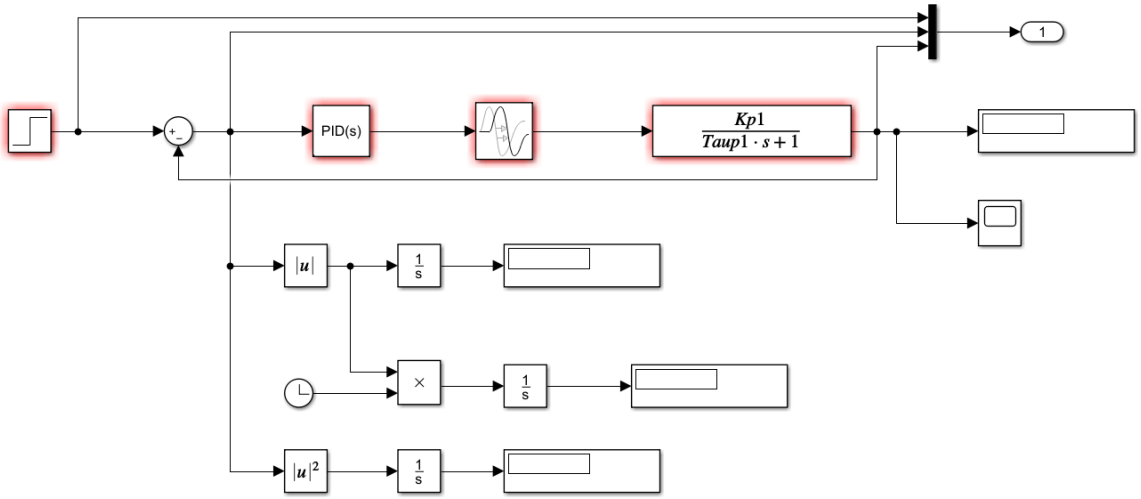

Figure-4. Closed-loop simulink model of the process.

3. RESULTS AND DISCUSSIONS

3.1 Steady State Simulation Results

The results obtained from the steady-state simulation of the developed Aspen PLUS model of the bio-ethylene process are given in Tables 4 and 5.

Table-4. Calculated parameters of product mole fractions in the stoichiometric reactor.

Product	Mole fraction
Ethanol	0.05263
Ethene	0.47368
Water	0.47368

Table-5. Calculated parameters of product mole fractions in the RADFRAC column.

Product	Column
Ethanol	0.029775
Ethene	0.947368
Water	0.022855

The results obtained and shown in Tables 4 and 5 revealed that ethene could be produced from ethanol as the mole fraction of the desired product (ethene) coming out of the column was very high.

3.2 Sensitivity Analysis Results

For an ethanol mole fraction in feed of 1, the results given in Table-6 were obtained when the distillate-to-feed ratio was varied from 0.5 to 0.9 with a step size of 0.01.

Table-6. Table showing results from the sensitivity analysis.

D/F Ratio	Mole fraction
0.5	0.947368415
0.51	0.928792565
0.52	0.910931172
0.53	0.893743794
0.54	0.877192983
0.55	0.861244027
0.56	0.845864662
0.57	0.831024931
0.58	0.816696915
0.59	0.802854594
0.6	0.789473684
0.61	0.776531493
0.62	0.764006791
0.63	0.751879699
0.64	0.740131579
0.65	0.728744939
0.66	0.717703349
0.67	0.706991359
0.68	0.696594427
0.69	0.686498856
0.7	0.676691729
0.71	0.66716086
0.72	0.657894737
0.73	0.64888248
0.74	0.640113798
0.75	0.631578947
0.76	0.623268698
0.77	0.615174299
0.78	0.607287449
0.79	0.599600266
0.8	0.592105263
0.81	0.584795322
0.82	0.577663671
0.83	0.570703868
0.84	0.563909774
0.85	0.557275542
0.86	0.550795594
0.87	0.54446461
0.88	0.538277512
0.89	0.53222945
0.9	0.526315789

Figure-5 shows the response of the top product composition to a change in distillate-to-feed ratio and the mole fraction of ethylene was observed to reduce with an increased distillate-to-feed ratio. Aspen Plus showed an error going outside the distillate-to-feed ratio of 0.5 and 0.9 and the maximum composition achieved was 0.947368415, hence the need for control strategies to achieve the desired composition of at least 0.9999.

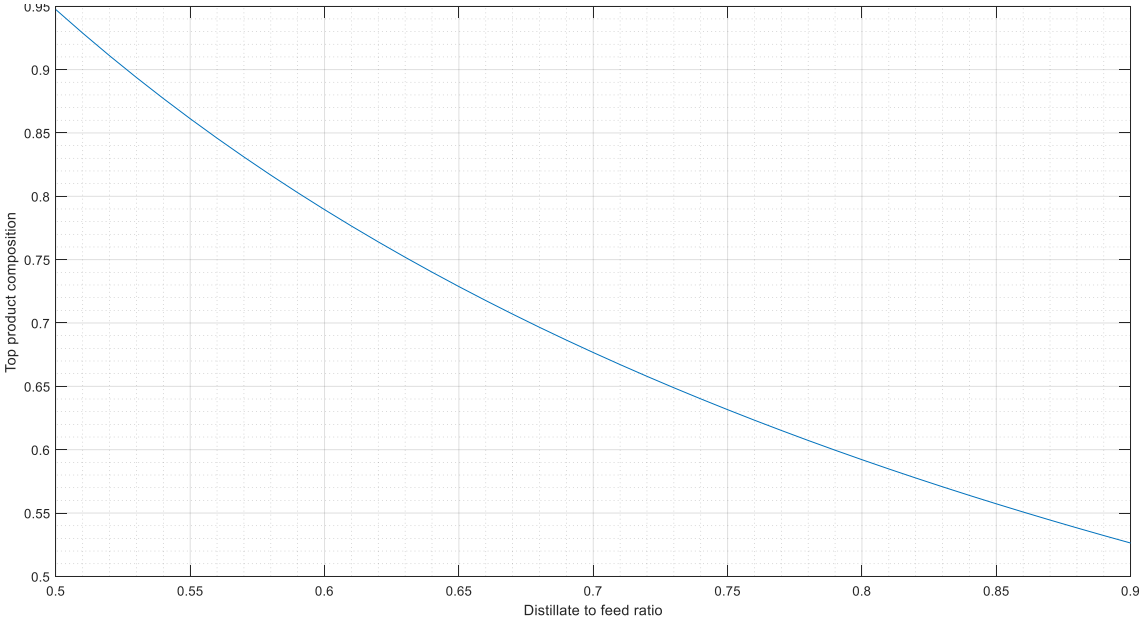

Figure-5. Response of ethylene top product composition to distillate to feed ratio.

3.3 Process Control Results

3.3.1 Open-loop simulation results

Using the developed MATLAB script code (Appendix A), the process overall transfer function relating ethylene mole fraction in the column distillate(controlled output variable) to the column distillate to feed ratio (selected manipulated variable) was obtained to be as given in Equation 4.

$$G_p(s) = \frac{0.04596e^{-0s}}{45.876s+1} \quad (4)$$

After applying a unit step change to the process manipulated variable using the developed transfer function, with the aid of Simulink, the open loop response of the process output was obtained, and it is given in Figure-6.

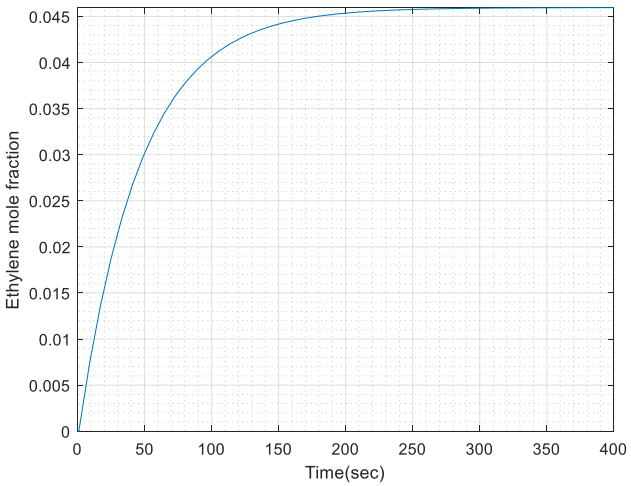

Figure-6. Open loop response of the process.

From the plot shown in Figure-6, it was observed that a steady state value of 0.0456 was achieved at approximately 250 mins and remained so as the time increased. The open-loop response made it clear that there was the need to control the system to have a product with higher mole fraction.

3.3.2 Controller tuning results

Using the P, PI, and PID control approaches, with the aid of the MATLAB code (Appendix C) and the process transfer function relating the distillate to feed mole ratio to ethylene mole fraction, the obtained tuning parameters as estimated using Tyreus-Luyben, and

Ziegler-Nichols tuning techniques were as shown in the Tables 7 and 8, respectively.

Table-7. Results from Tyreus-Luyben tuning technique.

Controller	Kc	T_I	T_D
P	-	-	-
PI	979.98	4.4018	
PID	1425.4	4.4018	0.31759

Table-8. Results from Ziegler-Nichols tuning technique.

Controller	Kc	T_I	T_D
P	1568		
PI	1425.4	1.6673	
PID	1844.7	1.0004	0.2501

3.3.3 Closed-loop response for set-point tracking

The results obtained when the Tyreus-Luyben tuning method was used are shown in Figure-7.

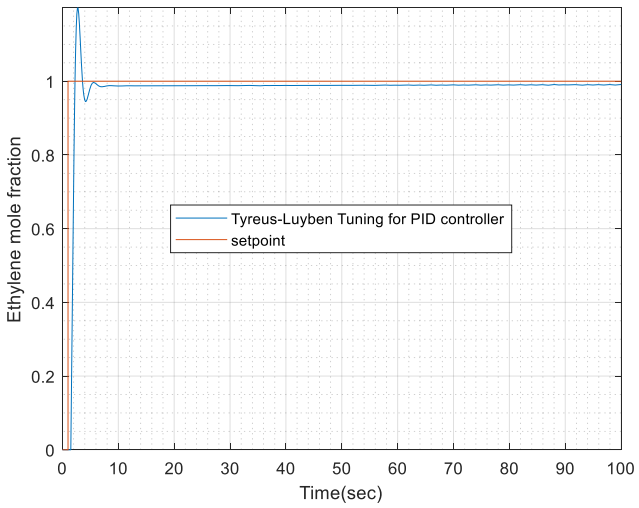

Figure-7. Closed-loop response with Tyreus-Luyben tuning parameters for a PID controller.

From the results given in Figure-7, applying Tyreus-Luyben tuning parameters for a PID controller could not make the system reach the desired set point of 1 for ethylene mole fraction, and the response was found to be unrealistic because, at a point in time, it exceeded the maximum mole fraction of 1.

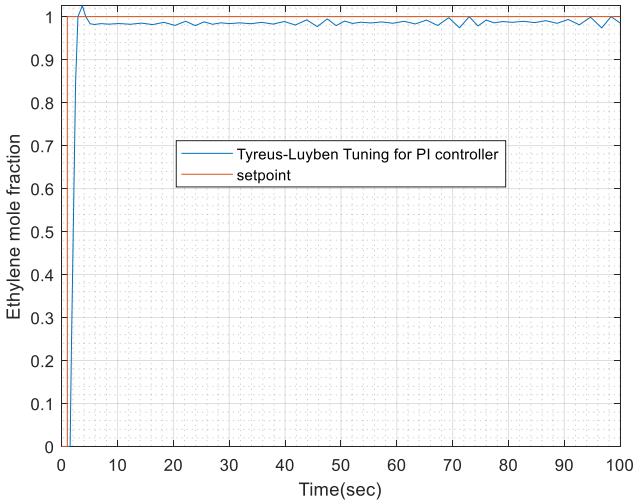

Figure-8. Closed-loop response with Tyreus-Luyben tuning parameters for a PI controller.

Considering Figure-8, similar to what was obtained in the case of PID tuned with the Tyreus-Luyben technique, applying Tyreus-Luyben tuning parameters for a PI controller was found not to be able to make the system get to the desired set-point of 1 for the ethylene mole fraction. The response was also found to be unrealistic because it exceeded the maximum mole fraction of 1.

Figure-9 shows the closed-loop response with Ziegler-Nichols tuning parameters for a PID controller. The response could not reach the desired setpoint either, and it was found to be unrealistic as the oscillations exceeded the maximum value of 1.

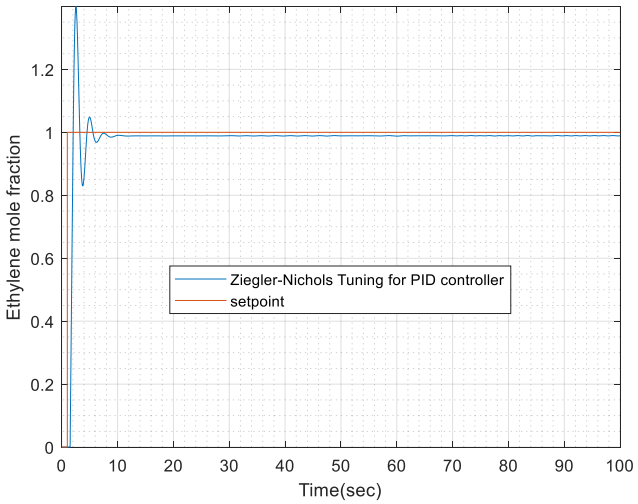

Figure-9. Closed-loop response with Ziegler-Nichols tuning parameters for a PID controller.

Figure-10 shows the closed-loop dynamic response with Ziegler-Nichols tuning parameters for a PI controller. The response also could not reach the desired setpoint, apart from being unrealistic as the oscillations exceeded the maximum value of 1.

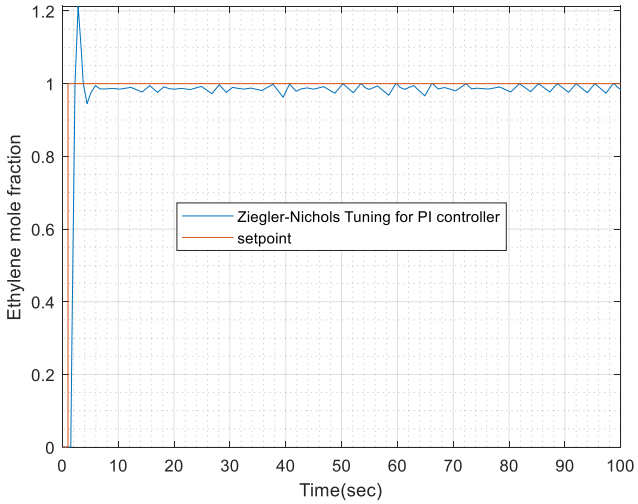

Figure-10. Closed-loop response with Ziegler-Nichols tuning parameters for a PI controller.

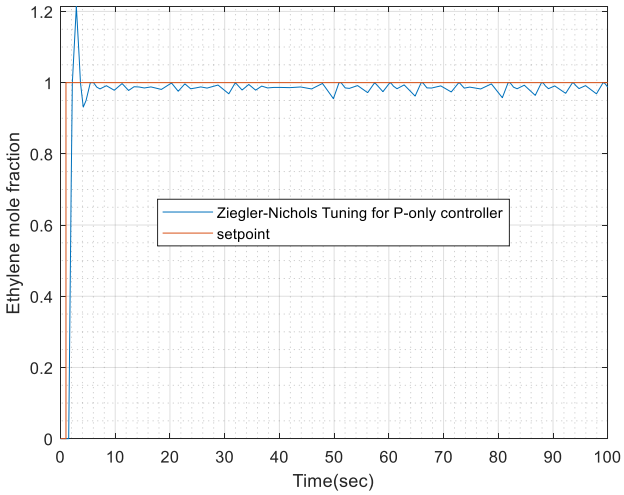

Figure-11. Closed-loop response with Ziegler-Nichols tuning parameters for a P-only controller

Figure-11 shows the closed-loop response with Ziegler-Nichols tuning parameters for a P-only controller. The response could not attain the desired setpoint, and it was also found to be unrealistic as the oscillations exceeded the maximum value of 1.

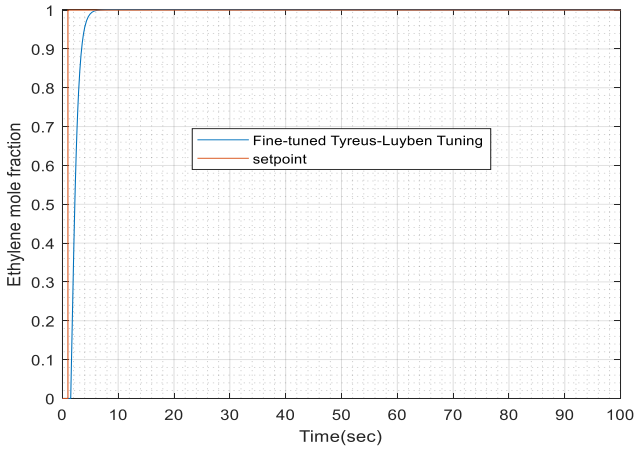

Figure-12. Closed-loop response with fine-tuned Tyreus-Luyben parameters for a PID controller.

Figure-12 shows the closed-loop response obtained when the Tyreus-Luyben parameters were fine-tuned for a PID controller. In this case, the parameters used for the tuning of the system for the control were the ones obtained from the modified Tyreus-Luyben parameters.

3.4 Controller Performance Evaluation

The integral absolute error (IAE), integral squared error (ISE) and integral time absolute error (ITAE) were the performance criteria used to check the efficiency of the Tyreus-Luyben, Ziegler Nichols, and fine-tuned Tyreus-Luyben methods for the P, PI, and PID controller.The integral absolute error, integral squared error, and integral time absolute error are the criteria employed for selecting the best controller. The controller form with the smallest values of IAE, ISE, and ITAE would be expected to give the best response. The values obtained for the criteria used in this work are given in Table-11, respectively, for the P-only, the PI, and the PID controllers.

Table-9. IAE, ISE and ITAE results for a P-only controller.

Tuning Technique	IAE	ISE	ITAE
Tyreus-Luyben	-	-	-
Ziegler-Nichols	2.471	0.6701	74.62
Modified Tyreus-Luyben	-	-	-

Table-10. IAE, ISE and ITAE results for a PI controller.

Tuning Technique	IAE	ISE	ITAE
Tyreus-Luyben	2.435	0.8076	68.01
Ziegler-Nichols	2.433	0.7191	71.46
ModifiedTyreus-Luyben	-	-	-

Table-11. IAE, ISE and ITAE results for a PID controller.

Tuning Technique	IAE	ISE	ITAE
Tyreus-Luyben	2.119	0.7753	54.75
Ziegler-Nichols	2.298	0.8078	57.52
Modified Tyreus-Luyben	1.474	1.022	4.767

From the graphical dynamic response of the set-point tracking, the PID controller with fine-tuned Tyreus-Luyben parameters was discovered to give the desired result. Now, looking at Tables 9-11, the IAE and ITAE values of the modified Tyreus-Luyben PID controller were estimated to be the lowest compared with those of the other ones, although the ISE value was a little bit higher than each of the other ones. Hence, it was found that this controller could be adopted for this process.

4. CONCLUSIONS

The results obtained from this work carried out on evaluating the performance of a P-only, PI, and PID controller in achieving a mole fraction of 1 as the top product of the distillation column for bio-ethylene production, it was discovered that the open-loop simulation gave a steady-state value of 0.04596 as opposed to the desired value of 1. Moreover, the results obtained from the open-loop simulation of the process showed that the system was stable as it was able to get to a steady state during the simulation period considered. Furthermore, the application of the PID controller tuned with modified Tyreus-Luyben parameters could make the process get to its set point.

Based on the experience gathered from carrying out this work, it is recommended that:

- the PID controller should be tested in a real plant to study its effect under disturbances,
- a model should be developed to study the disturbance rejection characteristics of the controller and select the best controller for a real-scale plant, and
- since the PID controller was fine-tuned from the standard Tyreus-Luyben parameters, an advanced control system like the model predictive controller (MPC) should be tested to validate the results obtained from this PID controller.

ACKNOWLEDGMENT

Special appreciation goes to Ambassador Aare Afe Babalola, LL.B, FFPA, FNIALS, FCIArb, LL.D, SAN, OFR, CON - The Founder and President, and the Management of Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria for providing a very conducive environment that enabled the accomplishment of this research work.

REFERENCES

[1] Aspen. 2019. Aspen Plus V11 (37.0.0.395). Aspen Technology, USA.

[2] Bi J., Guo X., Liu M., Wang X. 2010. High Effective Dehydration of Bio-Ethanol Into Ethylene over Nanoscale HZSM-5 Zeolite Catalysts. Catalysis Today. 149(1-2): 143-147.

[3] Bullem F. I.-O. 2021. Modelling, Simulation and Control of a Bio-Ethylene Production Process. B.Eng. Project Submitted to Afe Babalola University, Ado-Ekiti, Ekiti State, Nigeria.

[4] Giwa A. 2016. PI And PID Control of a Fuel Additive Reactive Distillation Process. ARPN Journal of Engineering and Applied Sciences. 11(11): 6779-6793.

[5] Giwa A., Chijioke C. M. and Giwa S. O. 2018. Modelling, Simulation And Dynamic Matrix Control of a Methanol-to-Ethene Process. Petroleum and Coal. 60(6): 060-1071.

[6] INFORSE. 2008. Sustainable Energy. International Network for Sustainable Energy.

[7] MathWorks. 2018. MATLAB, The Language of Technical Computing, The MathWorks, Inc., Natick, USA.

[8] Mohsenzadeh A., Zamani A., Taherzadeh M. J. 2017. Bioethylene Production from Ethanol: A Review and Techno-economical Evaluation. ChemBioEng Reviews. 4(2): 75-91.

[9] Seader J. D., Henley E. J., Roper D. K. 2019. Separation Process Principles: With Applications Using Process Simulators, 4th Edition. 560 pages, Wiley, New York, USA.

[10] Wu C.-Y. and Wu H.-S. 2017. Ethylene Formation from Ethanol Dehydration Using ZSM-5 Catalyst. American Chemical Society (ACS) Omega. 2(8): 4287-4296.

[11] Zhang D., Wang R. and Yang X. 2008. Effect of P Content on the Catalytic Performance of P-modified HZSM-5 Catalysts in Dehydration of Ethanol to Ethylene. Catalysis Letters. 124: 384-391.

APPENDICES

APPENDIX A

```
command window
clear
clc
close all
bd close all
mdata = xlsread('DFRESULT2');
u = mdata(:,1);
yd = mdata(:,2);
system Identification
```

APPENDIX B

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
T final = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
T delay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf (num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
%Open loop
open ('PROJECTOL')
[t,x,y] = sim('PROJECTOL',[0 400]);
figure(1)
title('open loop plot')
plot(t,y(:,1))
S = polyfit(t,y(:,1),1);
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
```

APPENDIX C

```
command window
clear
clc
close all
bdclose all
Tstep = 1;
Tinitial = 0;
Tfinal = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
Tdelay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf(num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;

% Tyreus-Luyben Tuning for PID
P = Kcu/2.2;
I = 2.2*Pu;

% closed loop
open('PROJECTCL')
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plotusing Tyreus-Luyben PID Controller Tuning Method')
plot(t,y(:,3))
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Tyreus-Luyben Tuning for PID controller','setpoint','location','best')
```

APPENDIX D

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
Tfinal = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
T delay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf(num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin(Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
% Tyreus-Luyben Tuning for PI controller
P = Kcu/3.2;
I = 2.2*Pu;
% closed loop
open('PROJECTCL')
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plotusing Tyreus-Luyben PI Tuning Method')
plot(t,y(:,3))
```

```
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Tyreus-Luyben Tuning for PID controller','setpoint','location','best')
```

APPENDIX E

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
T final = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
Tdelay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf (num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
% fine tuning Tyreus-Luyben Parameters
P = 700;
I = 16;
D = 0.31759;
% closed loop
open('PROJECTCL')
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plotusing Fine-tuned Tyreus-Luyben Tuning Method')
plot(t,y(:,3))
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Fine-tuned Tyreus-Luyben Tuning','setpoint','location','best')
```

APPENDIX F

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
Tfinal = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
Tdelay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf (num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
% Zieger-Nichols Tuning for PID
P = Kcu/1.7;
I = Pu/2;
D = Pu/8;
% closed loop
open ('PROJECTCL')
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plot using Zieger-Nichols PID Controller Tuning Method')
plot(t,y(:,3))
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Ziegler-Nichols Tuning for PID controller','setpoint','location','best')
```

APPENDIX G

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
T final = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
T delay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf (num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
% Ziegler-Nichols Tuning for PI
P = Kcu/2.2;
I = Pu/1.2;
% closed loop
open('PROJECTCL')
```

```
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plotusing Zieger-Nichols PI Controller Tuning
Method')
plot(t,y(:,3))
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Ziegler-NicholsTuning for
PIcontroller','setpoint','location','best')
```

APPENDIX H

```
command window
clear
clc
close all
bd close all
T step = 1;
T initial = 0;
T final = 1;
Kp1 = 0.04596;
Taup1 = 45.876;
T delay = 0.5;
setpoint = 1;
feed concentration = 1;
num = Kp1;
den = [Taup1 1];
Gp = tf (num,den,'IODelay',0.5);
[Gm,Pm,Wcg,Wcp] = margin (Gp);
Kcu = Gm;
pi = 22/7;
Pu = (2*pi)/Wcg;
% Ziegler-Nichols Tuning for P
P = Kcu/2;
% closed loop
open('PROJECTCL')
[t,x,y] = sim('PROJECTCL',[0 100]);
figure(1)
title('Plotusing Zieger-Nichols P-only Tuning Method')
plot(t,y(:,3))
hold on
stairs(t,y(:,1))
xlabel('Time(sec)')
ylabel('Ethylene mole fraction')
grid on
grid minor
axis tight
legend('Ziegler-Nichols Tuning for P-only
controller','setpoint','location','best')
```