JURNAL IPTEK

MEDIA KOMUNIKASI TEKNOLOGI

homepage URL : ejurnal.itats.ac.id/index.php/iptek

Proportional Integral Controller of Deisobutanizer Distillation Column by Co-simulate of Aspen Plus Dynamics and Matlab Simulink

Zahrotul Azizah[1]

Chemical Engineering Department, Universitas Nahdlatul Ulama Sidoarjo, Indonesia[1]

ARTICLE INFORMATION

Jurnal IPTEK – Volume 26 Number 2, December 2022

Page:
131 – 140
Date of issue :
December 30, 2022

DOI:
10.31284/j.iptek.2022.v26i2.3425

ABSTRACT

One of the control problems that is a challenge for an engineer and the chemical industry itself is chemical processes which are closely related to nonlinear processes. The linear method is the choice for many researchers to overcome problems in nonlinear processes, namely the linearization technique. This causes uncertainty whether the controller is able to work on the actual nonlinear process. The purpose of this study is to integrate Aspen Plus Dynamics and Matlab Simulink to eliminate linearization in order to be able to control nonlinear processes optimally. The method used is to perform steady state and continued dynamics simulation in the case study of the deisobutanizer distillation. Then integration of Aspen Plus Dynamics with Matlab Simulink using AMSimulink. The results show that steady-state and dynamics simulations have been successfully carried out. Aspen Plus Dynamics and Matlab Simulink are integrated and able to run together. The controllers used include reflux drum level control, top column pressure control, and reboiler level control. The response results obtained in the co-simulation run well, the process response can perform setpoint tracking.

Keywords*: AMSimulink; aspen plus dynamics; deisobutanizer; integration; matlab simulink*

E-MAIL

[1]azizah.tkm@unusida.ac.id

PUBLISHER

LPPM- Adhi Tama Institute of Technology Surabaya
Address:
Jl. Arief Rachman Hakim No. 100, Surabaya 60117,
Tel/Fax: 031-5997244

ABSTRAK

Salah satu masalah pengendalian yang menjadi tantangan bagi seorang *engineer* dan industri kimia itu sendiri adalah proses kimia yang erat kaitannya dengan proses nonlinier. Metode linier menjadi pilihan banyak peneliti untuk mengatasi permasalahan pada proses nonlinier, yaitu teknik linierisasi. Hal ini menyebabkan ketidakpastian apakah pengontrol mampu bekerja pada proses nonlinier yang sebenarnya. Tujuan dari penelitian ini adalah untuk mengintegrasikan Aspen Plus Dynamics dan Matlab Simulink untuk menghilangkan linearisasi agar dapat mengontrol proses nonlinier secara optimal. Metode yang digunakan adalah dengan melakukan simulasi *steady-state* dan dinamika proses pada studi kasus distilasi deisobutanizer. Kemudian integrasi Aspen Plus Dynamics dengan Matlab Simulink menggunakan AMSimulink. Hasil penelitian menunjukkan bahwa simulasi *steady-state* dan dinamika telah berhasil dilakukan. Aspen Plus Dynamics dan Matlab Simulink terintegrasi dan dapat berjalan bersama. Pengendali yang digunakan meliputi pengendali level reflux drum, pengendali tekanan kolom atas, dan pengendali level reboiler. Hasil respon yang didapat pada co-simulation berjalan dengan baik, respon proses dapat melakukan tracking setpoint.

Kata kunci: *AMSimulink; aspen plus dynamics; deisobutanizer; integration; matlab simulink*

INTRODUCTION

The chemical industry processes raw materials into products with high economic value in large quantities. In the process, there is a strong interaction between process variables, different operating conditions, causing the importance of designing reliable controllers to maintain environmental safety, maximize production yields, and minimize operating costs.

Most chemical processes are closely related to nonlinear processes, many physical processes are represented by nonlinear models so that control issues become a challenge for engineers and the chemical industry itself. Many researchers choose to use the linear method to overcome the problem of nonlinear controllers by means of linearization. Linearization techniques are limited in controlling chemical processes with a high degree of nonlinearity [1]. The most common thing is that there is an inconsistency between the model and the existing process. The model will not always be able to represent the process as a whole because the process is often affected by many disturbances that cannot be identified.

So far, the research is simulating a process using Aspen Plus and controlling the process that has been built in Aspen Plus using Matlab Simulink separately. The process model taken from Aspen Plus is linearized so that the process model does not represent the actual process. The discrepancy between the nonlinear process and the linear process model causes the controller design used to not control the process as a whole. Therefore, this research will integrate Aspen Plus Dynamics and Matlab Simulink as an effort to eliminate linearization techniques so that nonlinear processes can be controlled optimally. The integration process of Aspen Plus Dynamics and Matlab Simulink can be run simultaneously. This means that the processes built in Aspen Plus Dynamics in real time can be controlled using Matlab Simulink.

In previous research, Hu et al. (2012) simulated extractive distillation of Methyl Cyclohexane and Toluene (MCH) using Aspen Plus Dynamics which was used to evaluate and validate the usefulness of the nonlinear IMC strategy [2]. Dynamic simulation using Aspen Plus Dynamics and Matlab. The MCH distillation configuration is built into Aspen Plus Dynamics to define process operations under certain conditions. In real time, Aspen Plus Dynamics and Matlab Simulink are synchronized through the Aspen Modeler simulation block with the file name AMSimulation in the Matlab directory. The simulation results show effectiveness and good performance with setpoint tracking capabilities and interference rejection [2]. The same thing was done by Diaz (2014) who simulated a jacketed continuous stirred tank reactor (JCSTR) by integrating Aspen Plus Dynamics and Matlab Simulink [3]. In his next research, Diaz simulated the Dividing Wall Column (DWC) as an alternative to a very complex and integrated process with strong interactions. Steady state simulation using Aspen Plus which is then exported to dynamic models. The actual dynamic model was created using the AMSimulation block [4].

The use co-simulation between Aspen Plus Dynamics and Matlab Simulink was chosen because the benefits are significant [5][6][7]. One of the simulated processes is the distillation column. Because the distillation column can represent a complex nonlinear process [8][9][10]. The development of a predictive control model (MPC) for the vinyl chloride monomer (VCM) process using co-simulation between MATLAB Simulink and Aspen Plus Dynamics has been investigated. Co-simulation has the ability to design MPC controllers [11].

Aspen Plus software provides a special platform for dynamic simulation, namely Aspen Plus Dynamic Module, where the results from steady simulations can be brought to the dynamic module, while Matlab Simulink has configuration for the control system. The two software can be interfaced or integrated to be used together, namely real plant simulations or rigorous models from the Aspen Plus Dynamics platform and control system configurations from Matlab Simulink.

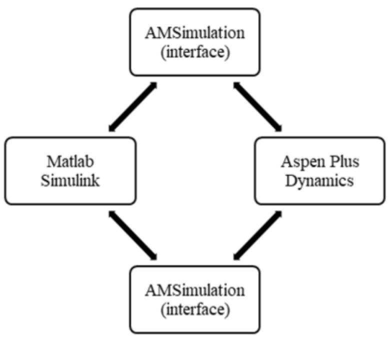

Figure 1. Interface flowchart between Aspen Plus Dynamics and Matlab Simulink

In this study, proportional integral controller is used to control the deisobutanizer column distillation process using a co-simulation approach between Aspen Plus Dynamics V.11 and Matlab Simulink R2014b. This case study involves binary distillation columns, process modeling, steady state simulation in Aspen Plus, importing steady-state models from Aspen Plus to Aspen Plus Dynamics, and designing and testing controllers in Aspen Plus Dynamics and MATLAB Simulink. Co-simulation using PI controller as in Aspen Plus Dynamics.

METHOD

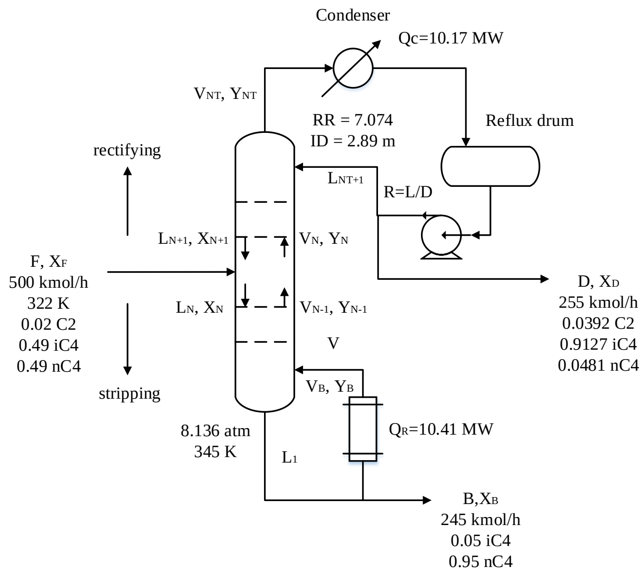

Figure 2. Design distillation Column deisobutanizer

Distillation columns are used in industry as multivariable, nonlinear and complex process [12]. Rigorous modeling is used to describe the distillation column process which is expressed by the equation (1) to (12) as follow [13][14]:

Overall Mass balance:

$$dM_N/dt = L_{N+1} - L_N + V_{N-1} - V_N \quad (1)$$

Component mass balance:

$$d(M_N X_N)/dt = L_{N+1}X_{N+1} - L_N X_N + V_{N-1}Y_{N-1} - V_N Y_N \quad (2)$$

Energy balance

$$d(M_N h_N)/dt = L_{N+1}h_{N+1} - L_N h_N + V_{N-1}H_{N-1} - V_N H_N \quad (3)$$

Condenser:

Mass balance

$$dM_D/dt = V_{NT} - L_{NT+1} - D \quad (4)$$

Component mass balance

$$d(M_D X_D)/dt = V_{NT}Y_{NT} - (L_{NT+1} + D)X_D \quad (5)$$

Energy balance

$$d(M_D h_D)/dt = V_{NT}H_{NT} - L_{NT+1}h_{NT+1} - Dh_D - Qc \quad (6)$$

Reboiler:

Mass balance

$$dM_N/dt = L_1 - V_B - B \quad (7)$$

Component mass balance

$$d(M_B X_B)/dt = L_1 X_1 - V_B Y_B - BX_B \quad (8)$$

Energy balance

$$d(M_B h_B)/dt = L_1 h_1 - V_B H_B - Bh_B - Q_R \quad (9)$$

Feed:
Mass balance
$$dM_{NF}/dt = L_{NF+1} - L_{NF} + F + V_{NF-1} - V_{NF} \quad (10)$$
Component mass balance
$$d(M_{NF}X_{NF})/dt = L_{NF+1}X_{NF+1} - L_{NF}X_{NF} + V_{NF-1}Y_{NF-1} - V_{NF}Y_{NF} + FX_F \quad (11)$$
Energy balance
$$d(M_{NF}h_{NF})/dt = L_{NF+1}H_{NF+1} - L_{NF}h_{NF} + V_{NF-1}H_{NF-1} - V_{NF}H_{NF} + Fh_F \quad (12)$$

There are 4 main stages carried out in this study, for the first steady state simulation, second dynamics simulation, third integration of aspen plus dynamics and matlab simulink, and the last setting controller. The case studies used in this study is a deisobutanizer distillation processs [15].

Steady-State Simulation

Perform steady state simulation on the distillation process for separating propane and isobutane using Aspen Plus software. The steady state simulation stage is as follows:

1) Configure the main equipment, namely the distillation column
2) Adding chemical components to be used
3) Choose the appropriate physical properties based on the components used
4) Specify the properties of each stream in the form of flow rate, composition, temperature, and pressure
5) Perform parameter specifications for each tool
6) Run when the data is complete. If the results have not converged, then check the tool or stream that has a warning or error.

Dynamics Simulation

The selected dynamics mode is Flow Driven. Next Aspen will create a new file in dynamics mode.

Aspen Plus Dynamics Integration with Matlab Simulink

1) Opening AMSimulation file in Matlab Simulink
2) Import the Aspen Plus Dynamics file that was done in the previous step into Matlab Simulink via the AMSimulation block
3) Integrating Aspen Plus Dynamics files with Matlab Simulink
4) Add process input and output. Integration is said to be successful if both software are running according to the set simulation time

Controller

Add a controller to the AMSimulation block to control the processes that have been built in Aspen Plus Dynamics. PI controller is not only used in Aspen Plus Dynamics but also in Co-simulation to control reflux drum level, top column pressure, and reboiler level. All PI controllers are tuned to get the best value control parameters. Tuning is done one by one using the tuning buttons available in Aspen Plus Dynamics.

The PI controller is the most popular variation, even more popular than the PID controller. The controller output value u(t) is fed into the system as the manipulated variable input.
$$u(t) = u_{bias} + K_c e(t) + \frac{K_c}{\tau_I}\int_0^t e(t)dt \quad (13)$$
The u_{bias} term is a constant that is usually set to the value u(t) when the controller is first switched from manual mode to automatic mode. The tuning parameter values for the PI controller are the controller gain (Kc) and the integral time constant (τ_I). The value of Kc is the multiplier of the proportional error and the integral term. The set point (SP) is the target value and the process variable (PV) is the measured value that may deviate from the desired value. The error of the set point is the difference between SP and PV and is defined as:
$$e(t) = SP - PV \quad (14)$$

RESULTS AND DISCUSSION

Steady-state deisobutanizer simulation was carried out. The first step is to input components consisting of ethane, isobutane, and n-butane. Then choose the thermodynamic property, namely Chao-Seader, because almost all hydrocarbon systems can be handled well by Chao-Seader [16]. Next, enter the operating conditions in the distillation column which include an inlet flow rate of 500 kmol/h, a pressure of 20 atm, a temperature of 322 K, a composition of 2% mole of ethane, 49% mole of isobutane and 49% mole of n-butane. Picture of the simulation results can be seen in fig. 3. Stream 1 is the feed entering the distillation column, stream 2 is the top product, while stream 3 is the bottom product. The steady-state simulation was successfully run using the aspen plus software.

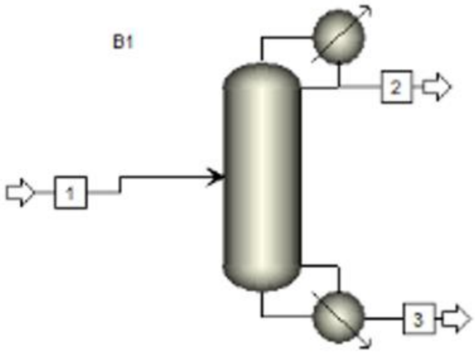

Figure 3. Steady-state simulation

Furthermore, the steady-state simulation results were validated to compare the simulation results with the literature design data in table I.

Table 1. Validation of steady-state simulation sesult with literature data [15]

Component	Design Data	Simulation Result	*Error* (%)
Composition of distillate (mole frac.)			
C_2	0.0392	0.03921	-0.000255
iC_4	0.9127	0.91274	-4.38E-05
nC_4	0.0481	0.04804	0.001247
Composition of bottom (mole frac.)			
C_2	0	0	0
iC_4	0.05	0.05	0
nC_4	0.95	0.95	0
Condenser duty (MW)	10.17	10.1484	0.002123
Reboiler duty (MW)	10.41	10.3863	0.002277

Based on the comparison of design data and simulation results, the results obtained indicate that the steady state simulation is not much different from the design data with a maximum error of 0.002%. So it can be said that the steady state simulation can represent the processes that exist in the literature.

After validating, it is continued by designing specification and vary which aims to determine the desired value of several controlled and manipulated variables. The simulation will adjust the manipulated variable in such a way that a certain value of the controlled variable is reached [16]. In this case, the design specification is the mole purity iC_4 is 0.05 on the bottom product. The design vary is the reflux ratio with the lower bound is 7 while the upper bound is 8. The result of this design is the composition of the bottom product is 5 mol% isobutane.

Process dynamics means situations change or processes change over time. In particular, when the input of the process changes, how will the output variable respond over time. Most dynamic processes are concerned with the systematic characterization of the time response of the affected variables to changes in the causal variables. The affected variable is also referred to as the output variable, and the causal variable is also usually referred to as the input variable [17].

Aspen Plus Dynamics is a simulator for dynamic processes that is used to understand the dynamic behavior of a process. Aspen Plus Dynamics is tightly integrated with Aspen Plus which is a simulator for steady-state. This makes it possible to create dynamic simulations from steady-state simulations that have been created in Aspen Plus. The integration process of Aspen plus Dynamics and Matlab Simulink has been studied and understood how to implement it. AMSimulink in the form of Aspen Modeler block is an important key in integrating the two software. On the aspen modeler block, there is an input file menu. In this menu, input the distillation column simulation using Aspen Plus Dynamics that has been done previously.

The input variable contains the information sent from matlab Simulink to the Aspen modeler block. This variable is usually called the manipulated variable. Meanwhile, the output variable contains the information received by matlab simulink from the Aspen modeler block. This variable is usually called a controlled variable. The manipulated variables are level on top column, pressure on top column, and level on base column. The controlled variables are flowrate on top product, condenser duty, and flowrate on bottom product.

The next step is add three controller blocks that will connect each one input variable and one output variable. When the dynamics simulation in the previous stage is successfully executed, by default it will display a controller with the Proportional Integral (PI) controller type that has been installed in the process. There are three controllers installed including reboiler level control, top column pressure control, and reflux drum level control. The three controllers installed on aspen plus dynamics are replaced with controllers on matlab simulink. The integration process of aspen plus dynamics and matlab simulink can be run simultaneously. Fig. 4 is a display of the aspen modeler block that has been connected to the controller.

After all controllers are installed, the simulation is run then simulations both matlab simulink and aspen plus dynamics will run simultaneously. The simulation results are responses from the controlled variables and manipulated variables from the three controllers. Controlled variable and manipulated variable are related to each other. If the controlled variable deviates from the setpoint, the controller will take corrective action by adjusting the manipulated variable in such a way that the controlled variable returns to its setpoint [18].

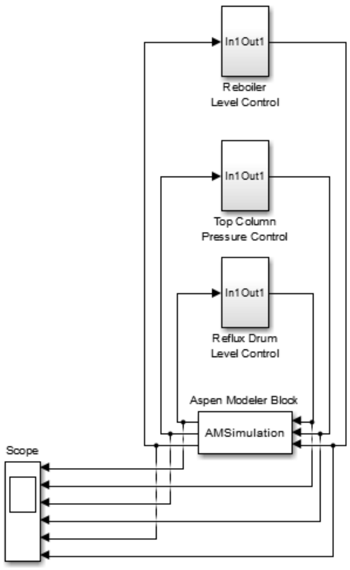

Figure 4. Aspen modeler block connected to controller

All PI controllers are tuned using the auto-tuning method in Aspen Plus Dynamics. It provides the best control parameters to reach the best control response. Set point changes have been made to the PI controllers respectively to investigate its effect on product purity. The PI controller parameters are shown in the table II.

Table 2. Controller parameter

Parameters	Proportional Gain (Kc)	Integral Time Constant (τ_I)
reflux drum level	0.0735	489.0701
top column pressure	0.6256	189.8475
reboiler level	0.0433	403.3922

Figures 5 and 6 show the controlled variable response and the manipulated variable response. In Figure 5, when the simulation is run the level in the top column increases but decreases again with settling time of 3.8 hour. When reflux drum level exceeds the setpoint, the controller takes corrective action by reducing flowrate on reflux drum so that the level can return to the setpoint. The setpoint value of 7.73125 m. The flowrate on the top product in Figure 6 descrease at 1 hour to maintain the level in the top column at the setpoint.

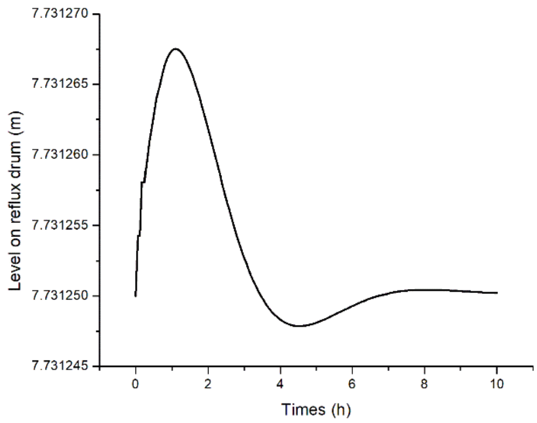

Figure 5. Controlled variable response (level) on reflux drum level control

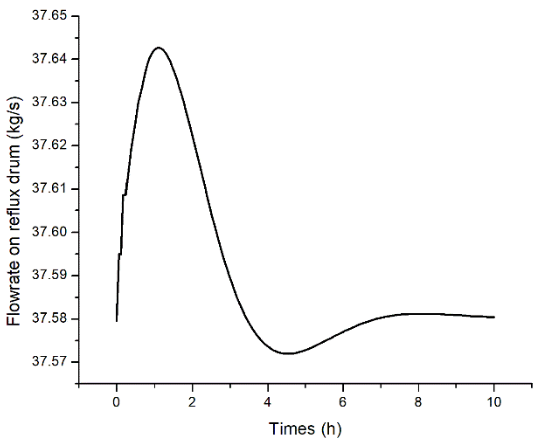

Figure 6. Manipulated variable (flowrate) response on reflux drum level control

In Figure 7, when the simulation is run the pressure on the top column increases but reaches the settling time in 0.9 hour. The setpoint value of 783748.88 N/m^2. Pressure on top column is related to the condenser duty. The increase in pressure on the top column causes the controller to take corrective action by reducing the condenser duty at 30 minutes to keep the pressure at its setpoint (Figure 8).

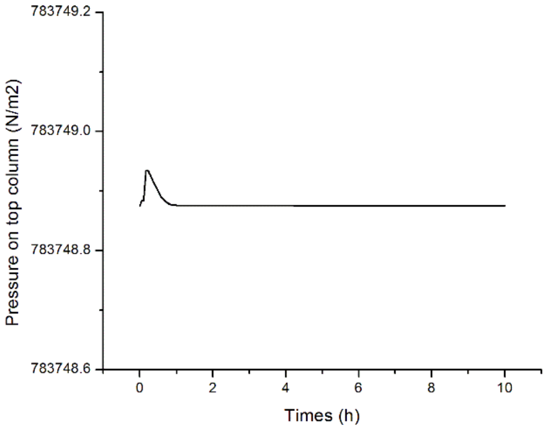

Figure 7. Controlled variable response (pressure) on top column pressure control

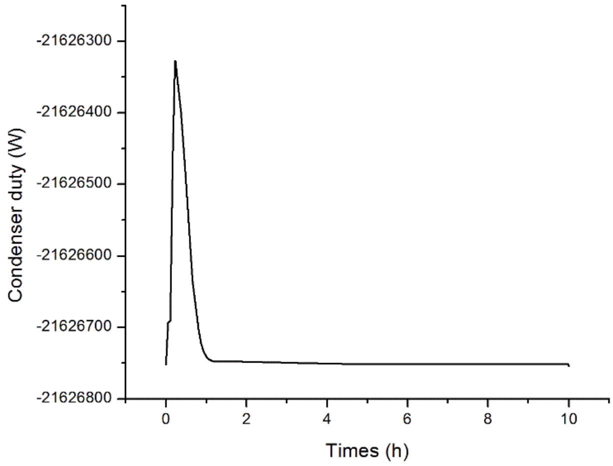

Figure 8. Manipulated variable response (condenser duty) on top column pressure control

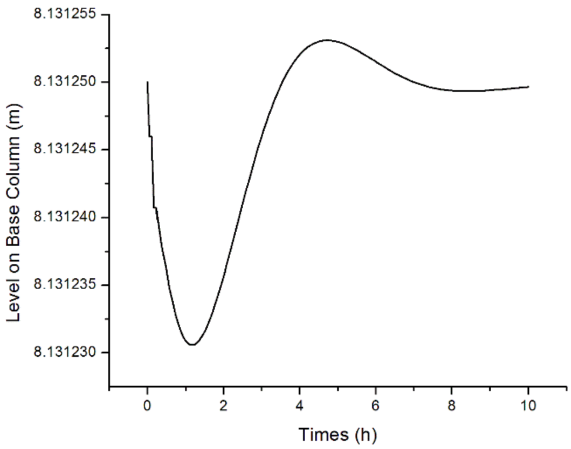

Figure 9. Controlled variable (level) response to reboiler level control

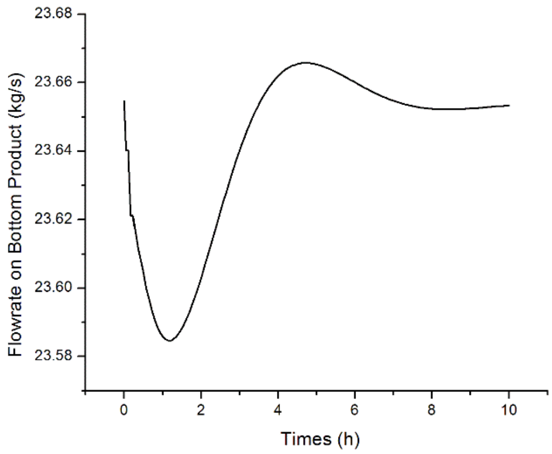

Figure 10. Manipulated variable (flowrate) response on reboiler level control

In Figure 9, when the level in the base column decreases, the PI controller takes corrective action by changing the manipulated variable by increasing the flowrate on reboiler level control so that the level returns to the setpoint (Figure 10). The setpoint value of 8.131248 m. Level on the base column reaches the settling time in 6.4 hour.

Simulation stops after response returns to setpoint again. The results show that the response between Aspen Plus Dynamics and Co-simulation give same results in every test. This indicates that the co-simulation was successfully carried out.

CONCLUSION

Steady-state and dynamics simulations on the deisobutanizer distillation process can be run well. The integration process between aspen plus dynamics and matlab simulink has been successfully carried out. There are three controllers installed, namely reflux drum level control, top column pressure control, and reboiler level control. All three controllers can control the process well. proven by the process can return to the setpoint and there is no steady-state error. In conclusion, the results obtained in Aspen Plus Dynamics and co-simulation are the same. This indicates that the co-simulation was successfully carried out.

REFERENCES

[1] B. W. Bequette, "Nonlinear Control of Chemical Processes: A Review," *Ind. Eng. Chem. Res.*, vol. 30, no. 7, hal. 1391–1413, 1991, doi: 10.1021/ie00055a001.

[2] B. Hu, Z. Zhao, dan J. Liang, "Multi-loop nonlinear internal model controller design under nonlinear dynamic PLS framework using ARX-neural network model," *J. Process Control*, vol. 22, no. 1, hal. 207–217, 2012, doi: 10.1016/j.jprocont.2011.09.002.

[3] I. Díaz dan M. Rodríguez, *On-line Fault Diagnosis by Combining Functional and Dynamic Modelling of Chemical Plants*, vol. 33. Elsevier, 2014.

[4] M. Rodríguez, P. Z. Li, dan I. Díaz, "A control strategy for extractive and reactive dividing wall columns," *Chem. Eng. Process. Process Intensif.*, vol. 113, hal. 14–19, 2017, doi: 10.1016/j.cep.2016.10.004.

[5] A. Briones-Ramírez dan C. Gutiérrez-Antonio, "Multiobjective Optimization of Chemical Processes with Complete Models using MATLAB and Aspen plus," *Comput. y Sist.*, vol. 22, no. 4, hal. 1157–1170, 2018, doi: 10.13053/CyS-22-4-3087.

[6] C. E. Degree dan A. E. Degree, "TRAINING COURSE IN SIMULATION OF CHEMICAL PROCESS Master thesis," no. June, 2020.

[7] P. Furda, M. Variny, Z. Labovská, dan T. Cibulka, “Process drive sizing methodology and multi-level modeling linking matlab® and aspen plus® environment,” *Processes*, vol. 8, no. 11, hal. 1–42, 2020, doi: 10.3390/pr8111495.

[8] V. Sakhre, “Distillation - Modelling, Simulation and Optimization,” *Distill. - Model. Simul. Optim.*, 2019, doi: 10.5772/intechopen.78212.

[9] N. Siraj dan A. Hakim, “Steady-State and Dynamic Simulations of Gas Absorption Column Using MATLAB and SIMULINK,” *Int. J. Math. Model. Comput.*, vol. 8, no. 3 (SUMMER), hal. 171–188, 2018,

[10] D. Hartanto *et al.*, “Simulation of the Extractive Distillation using Ethylene Glycol as an Entrainer in the Bioethanol Dehydration,” no. Eic 2018, hal. 450–454, 2020, doi: 10.5220/0009013004500454.

[11] J. Chinprasit dan C. Panjapornpon, “Model predictive control of vinyl chloride monomer process by Aspen Plus Dynamics and MATLAB/Simulink co-simulation approach,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 778, no. 1, 2020, doi: 10.1088/1757-899X/778/1/012080.

[12] S. Skogestad dan P. Lundström, “Mu-optimal LV-control of distillation columns,” *Comput. Chem. Eng.*, vol. 14, no. 4–5, hal. 401–413, 1990, doi: 10.1016/0098-1354(90)87016-I.

[13] J. A. Romagnoli, J. A. Romagnoli, A. Palazoglu, dan A. Palazoglu, *Plantwide Process Control*. 2020.

[14] Totok R. Biyanto, “Internal Model Control (IMC) - Neural Network (NN) Gain Scheduling untuk Pengendalian Kolom Distilasi,” *J. Tek. Elektro*, vol. 5, no. 2, hal. 73–79, 2005,

[15] W. L. Luyben, “Chemical Engineering and Processing : Process Intensification Design and control of dual condensers in distillation columns,” *Chem. Eng. Process. Process Intensif.*, vol. 74, hal. 106–114, 2013, doi: 10.1016/j.cep.2013.08.007.

[16] W. L. Luyben, *Distillation Design and Control Using Aspen Simulation*, Second Edi. Lehigh University, Bethlehem, Pennsylvania, 2013.

[17] M. Syahmi dan K. Sham, “Design and Co-simulate control of an Extractive Distillation Column Using Aspen plus Dynamics with MATLAB and Simulink Toolbox Thesis Report,” 2016.

[18] D. Seborg, T. Edgar, D. Mellicamp, dan F. Doyle III, “Process Dynamics and Control,” *John Wiley Sons*, hal. 595, 2011, doi: 10.1007/s13398-014-0173-7.2.