Revista ARACÊ
ISSN: 2358-2472

DYNAMIC SIMULATION INTEGRATION IN PROCESS CONTROL EDUCATION: A CASE STUDY ON METHANOL-WATER SEPARATION USING AVEVA PROCESS SIMULATION

https://doi.org/10.56238/arev7n1-061

Date of submission: 06/12/2024 **Date of publication:** 06/01/2025

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ABSTRACT

This study explores implementing a novel teaching methodology for process control education using AVEVA Process Simulation software. The methodology integrates interactive simulations and practical problem-solving exercises, focusing on the dynamic simulation of an ethanol-water distillation process. In this scenario, students are tasked with evaluating the performance of controllers integrated into the simulation, allowing them to engage with dynamic process behaviors in a virtual environment. The results indicate a significant improvement in students' understanding and assimilation of process control concepts. Feedback gathered through questionnaires, with six participants, highlighted the effectiveness of the adopted methodology. All six participants reported an enhanced understanding of PID controller tuning (average score of 4.83), demonstrating the positive impact on both practical and theoretical learning. This innovative teaching strategy demonstrates its potential to modernize process control education and bridge the gap between academic instruction and industrial applications.

Keywords: PID Control. Process Control Education. Aveva Process Simulation. Dynamic Simulation. Continuous Distillation.

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INTRODUCTION

Bridging the gap between theory and practice remains a primary challenge in chemical engineering education (JARAMILLO AND REYES, 2024). This challenge is particularly significant in process control, where the mathematical foundations of control theory often hinder practical demonstration to undergraduate students. To address this, the use of graphical and practical examples has proven highly effective in enhancing students' understanding of these complex concepts (RANADE, 2012).

To improve cognitive learning in process control, educators have introduced various simulation software tools, case studies, Project-Based Learning (PBL), and other innovative teaching methodologies (JARAMILLO AND REYES, 2024; DOMINGUES, 2010; ROMAN, 2025; SALAZAR-PEÑA, 2023). These approaches encourage students to engage actively with real-world applications, fostering a more integrated comprehension of theoretical principles. However, the limited instructional time available for this subject, combined with its extensive and complex content, underscores the necessity of adopting modern teaching strategies to optimize learning outcomes (BEQUETTE, 2019).

Dynamic system simulation plays a pivotal role in Process Control courses, aiding in process analysis and controller design. However, for undergraduate students, the computational demands of dynamic simulation often render it impractical for complex systems. This limitation can be addressed through simulators that simplify analysis while maintaining accuracy. Among these, AVEVA Process Simulation stands out for its robust dynamic process simulation capabilities and an extensive library of ready-to-use examples, making it particularly effective for educational purposes (AVEVA, 2024).

The integration of simulation software in engineering education has proven to be a transformative strategy, bridging the gap between theoretical knowledge and practical application. Simulation tools enable students to visualize complex systems, engage in problem-solving, and explore real-world scenarios within a controlled and interactive environment. Yusof et al. (2005) emphasize that interactive learning methods, such as simulation-based approaches, significantly enhance students' understanding of engineering principles by enabling them to experiment with system parameters and observe real-time impacts. This hands-on approach fosters critical thinking and deeper engagement with the subject matter. Similarly, Kolb and Kolb (2017) highlight that experiential learning environments provided by simulation software help develop higher-order cognitive skills, such as analysis, synthesis, and evaluation.

In process engineering, where mathematical modeling and dynamic system behavior are fundamental, simulation tools allow students to investigate complex systems that may be unsafe, financially burdensome, or time-intensive to study in real-life scenarios (KOMULAINEN et al., 2012). Tools like Aspen, Matlab, DWSIM, and AVEVA Process Simulation enhance the educational experience by enabling students to interact with realistic process simulations, fostering a deeper understanding of operational dynamics and control strategies.

Incorporating simulation into project-based learning further enhances student outcomes. Prince and Felder (2006) demonstrate that active learning methods combined with technological tools improve knowledge retention and application to practical problems. Through simulation-based projects, students collaborate, make decisions, and develop a comprehensive understanding of engineering systems, aligning their skills with industry demands for effective problem-solvers.

This study adopts Bloom’s Taxonomy as a framework for classifying cognitive learning objectives. Originally developed by Bloom et al. (1956), the taxonomy organizes learning into six hierarchical levels: Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating. This framework ensures a structured progression from foundational knowledge acquisition to advanced cognitive skills.

The case study presented here aims to guide students toward the Analyzing level of Bloom’s Taxonomy by enabling them to dissect complex information and identify relationships and patterns within the ethanol-water separation process. While the course has thus far focused on the Applying level, where students use theoretical knowledge to solve problems and operate simulation tools, this study seeks to deepen their understanding. By advancing to the Analyzing level, students will critically evaluate system behaviors, explore underlying mechanisms, and make data-informed decisions based on simulation results.

RESEARCH OBJECTIVES

Based on the points outlined above, this work addresses the following questions:

- How to Achieve the Cognitive Level of Analysis in the Process Control Curriculum Using Simulators?
- How can a methanol-water distillation process dynamic model improve students' understanding of the practical application of control theory concepts?

Thus, this study aims to propose a case study for students in the process control and instrumentation curriculum at the undergraduate level designed to address the questions mentioned above.

MATERIALS AND METHODS

The case study was implemented in the Process Control course within the Chemical Engineering program at the Federal University of Technology - Paraná. The study was conducted over 8 hours of classroom activities in a computer laboratory. To ensure its success, students must possess prior knowledge of key foundational topics, including transfer functions and their derivation from experimental data, an introduction to feedback control, the PID control law, and methods for controller tuning. The methodology adopted in this study was a case study centered on the methanol-water separation process, modeled using the AVEVA Process Simulation™ software. This approach enabled a detailed and practical exploration of the operational parameters and dynamics inherent to the separation process.

AVEVA PROCESS SIMULATION

AVEVA Process Simulation allows for steady-state and dynamic simulations, making it a versatile solution for designers, engineers, and researchers who analyze and optimize complex systems. Steady-state simulations analyze processes under stable conditions, while dynamic simulations enable studying system behavior over time, reflecting transitions and operational variations.

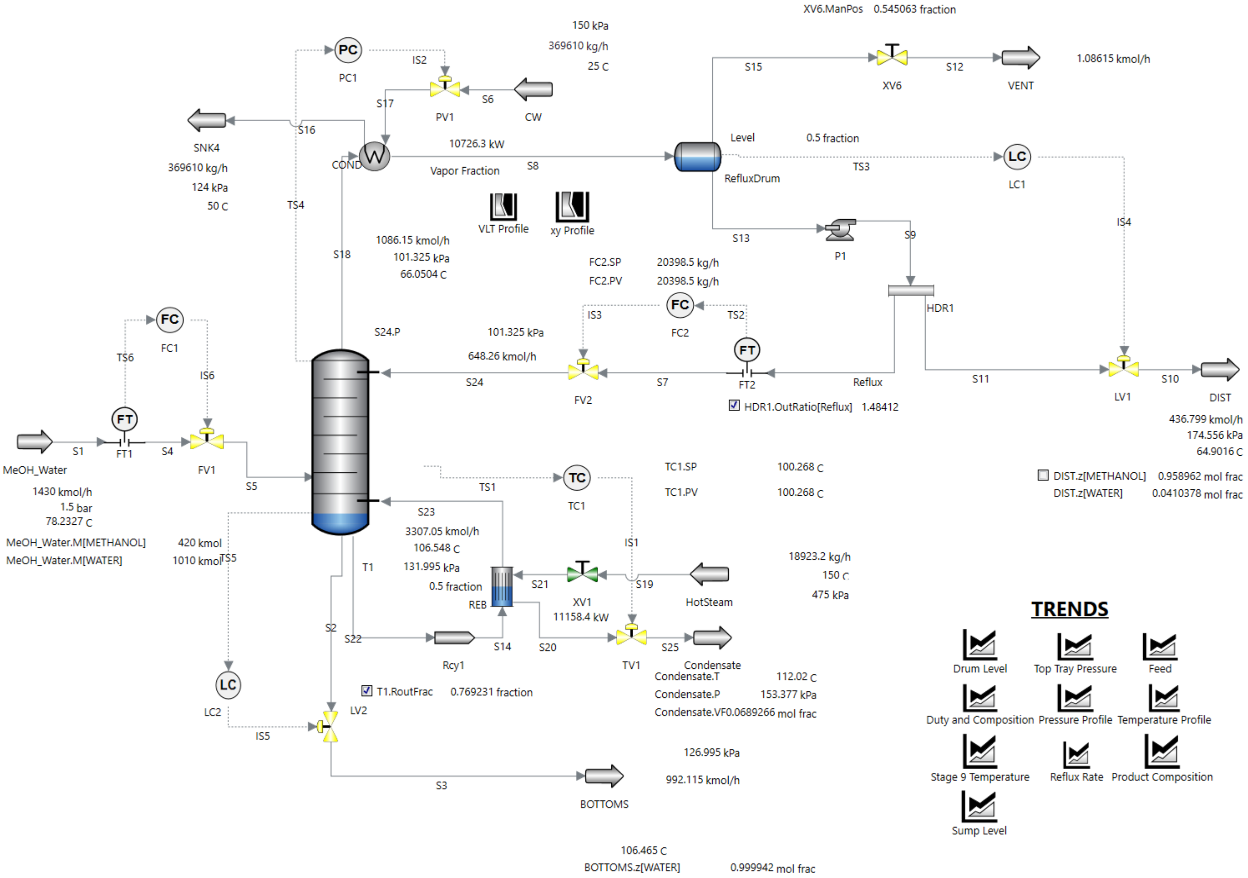
This work used version 2024.2 of AVEVA Process Simulation (AVEVA, 2024), which offers significant advancements compared to previous versions. One of the key features of this version is the ability to export dynamic data from the graphs generated within the simulator. This functionality is beneficial for in-depth analyses and detailed visualizations, facilitating the processing and interpreting of results obtained throughout the study.

AVEVA Process Simulation includes a comprehensive collection of pre-configured process examples and detailed documentation. These examples provide a robust starting point for various analyses and tests, serving as a foundation for academic and industrial applications.

ETHANOL WATER DISTILLATION DYNAMIC SIMULATION

For this work, the template "C1 - Water Methanol Separation Detailed Engineering" available in the software files (AVEVA, 2024), was selected (Figure 1). This model was chosen due to its relevance and complexity, allowing the exploration and validation of the software's functionality in detailed engineering scenarios.

Figure 1. Water-Methanol Separation Simulation with Clickable Tags and Variables.



Source: Prepared by the authors using AVEVA Process Simulation software.

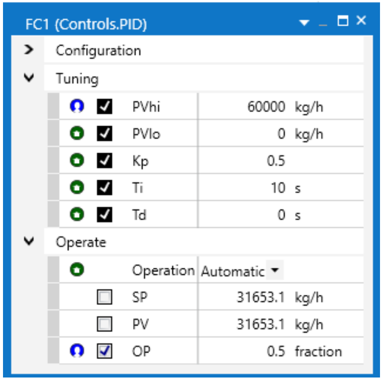
STEPS TO IMPLEMENT THE CASE STUDY

The procedure for the case study involves obtaining a dynamic model of the process in each control loop and establishing the relationship between the manipulated variable (OP) and the controlled variable (PV). The AMIGO controller tuning method (ASTROM; HAGGLUND, 2006) is applied to calculate the new controller constants, then its performance is evaluated. The steps carried out are as follows: obtaining the transfer function from simulation data, calculating new constants for PID control, and analyzing the performance of the new PID controller parameters.

step 1: obtaining the transfer function from simulation data

The process simulation includes five controllers identified by the following tags: FC1, FC2, PC1, TC1, LC2, and FC2 (Figure 1). The manipulated variables are represented as (OP), the controlled variables as (PV), and the setpoint as (SP) (Figure 2).

Figure 2. Configuration table image for controller FC1.



FC1 (Controls.PID)

> Configuration

˅ Tuning

☑	PVhi	60000	kg/h
☑	PVlo	0	kg/h
☑	Kp	0.5	
☑	Ti	10	s
☑	Td	0	s

˅ Operate

	Operation	Automatic	
☐	SP	31653.1	kg/h
☐	PV	31653.1	kg/h
☑	OP	0.5	fraction

Source: Prepared by the authors using AVEVA Process Simulation software.

FC1 controls the feed flow rate to the column, using the valve opening of FV1 as the manipulated variable (OP) and the mass flow rate measured by the FT1 sensor as the controlled variable (PV). The FC2 controller adjusts the opening of valve FV2 to control the flow rate (PV).

The TC1 controller regulates the temperature at stage 9 of the distillation column by opening valve TV1. This valve's opening directly affects the steam supplied to the reboiler, influencing the column's temperature. PC1 adjusts the opening of valve PV1 to control the column's top pressure. This valve modulates the flow rate of the cooling fluid in the condenser at the top of the column, directly affecting the pressure of the last stage.

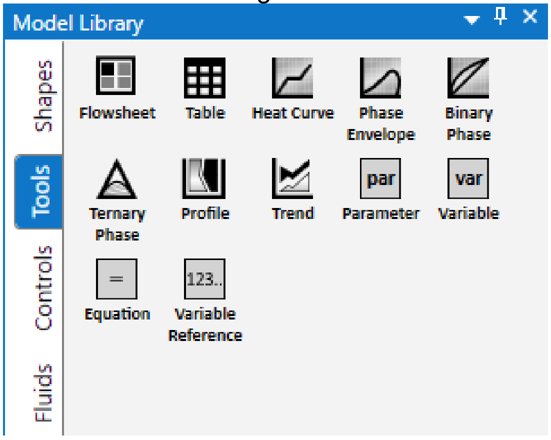
This model also includes two level controllers, LC1 and LC2. LC2 manipulates the opening of valve LV2 to control the liquid level at the column's base stage. Similarly, LC1 adjusts the opening of valve LV1 to control the liquid level in the reflux drum. Experimental open-loop data can be obtained for each controller to establish the relationship between the manipulated variable (OP) and the controlled process variable (PV). For the FC1 controller, the following steps were performed:

1. Open the example "C1 - Water Methanol Separation Detailed Engineering" (AVEVA, 2024). The simulation will initially be in Process mode.
2. Switch to Fluid Flow mode to update the simulation parameters for this condition, then select Dynamics mode.

3. The Dynamics mode enables dynamic system simulation and data recording using a Trend.
4. To add a Trend, navigate to the Tools section in the Model Library (Figure 3) and drag it into the simulation environment.

This setup allows for the capture and analysis of dynamic data to study the relationship between OP and PV.

Figure 3. Selection for adding a new trend to the simulation.

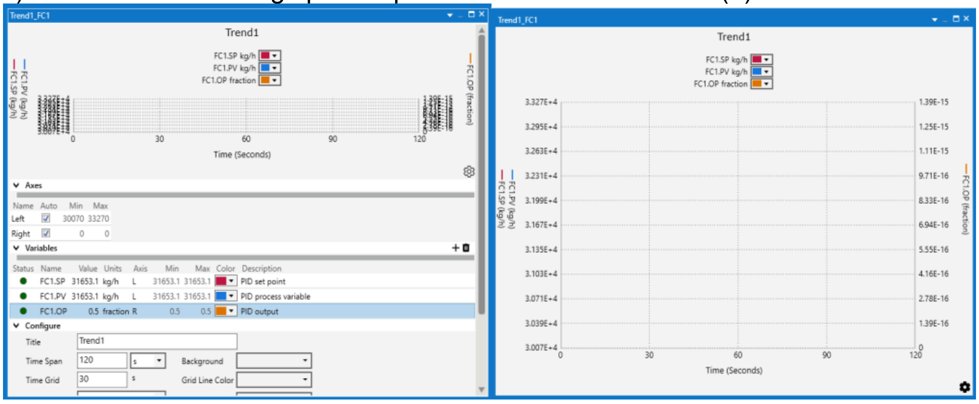


Source: Prepared by the authors using AVEVA Process Simulation software.

Any desired variable in the FC1 controller block can be "dragged" into the Trend to observe its behavior over time. For this analysis, the variables SP, PV, and OP were added to the Trend (Figure 2).

Once the variables were added, the Trend was opened, and the gear icon was clicked to access its settings (Figure 4a). The OP variable was assigned to the right axis of the graph. After configuring the Trend, the settings window was closed, leaving only the graph visible (Figure 4b).

Figure 4. (a) Trend with the settings panel open. (b) Trend with the settings panel



Axes

Name	Auto	Min	Max
Left	☑	30070	33270
Right	☑	0	0

Variables

Status	Name	Value	Units	Axis	Min	Max	Color	Description
●	FC1.SP	31653.1	kg/h	L	31653.1	31653.1	🟥	PID set point
●	FC1.PV	31653.1	kg/h	L	31653.1	31653.1	🟦	PID process variable
●	FC1.OP	0.5	fraction	R	0.5	0.5	🟧	PID output

Configure

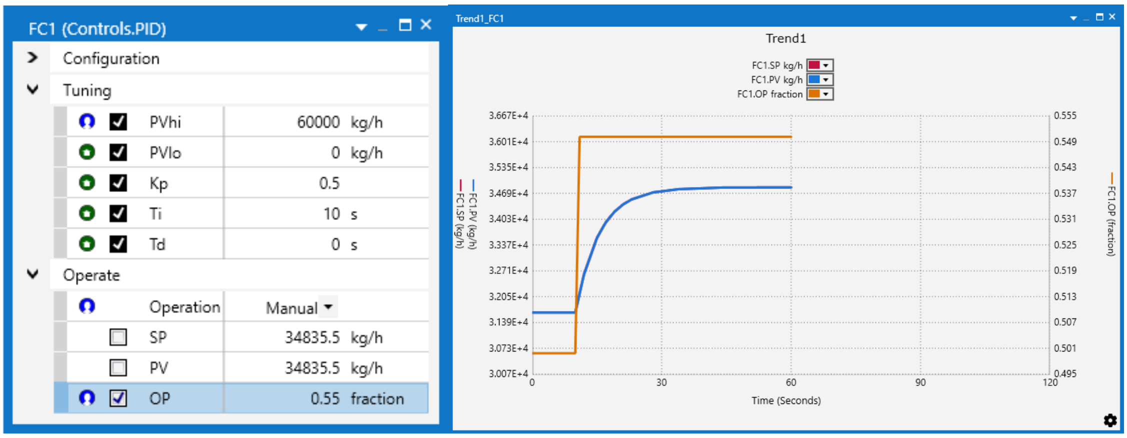
Title: Trend1
Time Span: 120 s
Background:
Time Grid: 30 s
Grid Line Color:

Source: Prepared by the authors using AVEVA Process Simulation software.

With the Trend configured, the dynamic simulation of the system begins to ensure it is in a steady state. In the FC1 controller, the operation mode is switched to manual (Figure 5a), allowing the manipulated variable to be directly specified by the user instead of calculated by the controller.

To start the simulation, click Run. After running the process for approximately 10 seconds, the manipulated variable (OP) is adjusted from 0.5 to 0.55, representing a +5% change relative to the valve's opening range, which spans from 0 to 1. The simulation continues until 60 seconds when the process reaches a new steady state for the specified variables (Figure 5b).

Figure 5. (a) Controller setup and step change in valve opening. (b) Mass flow rate response during the simulation.



FC1 (Controls.PID)

Configuration

Tuning

☑	PVhi	60000 kg/h
☑	PVlo	0 kg/h
☑	Kp	0.5
☑	Ti	10 s
☑	Td	0 s

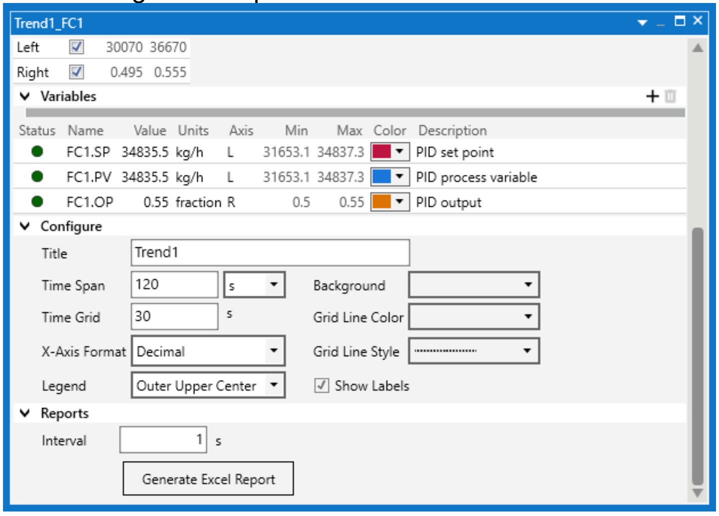
Operate

	Operation	Manual
☐	SP	34835.5 kg/h
☐	PV	34835.5 kg/h
☑	OP	0.55 fraction

Source: Prepared by the authors using AVEVA Process Simulation software.

The simulation data is then exported to an Excel file by clicking "Generate Excel Report" in the Trend settings (Figure 6). These data are used to apply a method for deriving a First-Order Plus Time Delay (FOPTD) transfer function from experimental data, as described by Seborg (2010). If the output data represents a second-order or higher transfer function, students should conduct a literature review to explore appropriate methods for obtaining this model type.

Figure 6. Exports simulation data to Excel.



Trend1_FC1

Left ☑ 30070 36670
Right ☑ 0.495 0.555

Variables

Status	Name	Value	Units	Axis	Min	Max	Color	Description
●	FC1.SP	34835.5	kg/h	L	31653.1	34837.3	🟥	PID set point
●	FC1.PV	34835.5	kg/h	L	31653.1	34837.3	🟦	PID process variable
●	FC1.OP	0.55	fraction	R	0.5	0.55	🟧	PID output

Configure

Title: Trend1
Time Span: 120 s
Time Grid: 30 s
X-Axis Format: Decimal
Legend: Outer Upper Center
Background:
Grid Line Color:
Grid Line Style: ……………
☑ Show Labels

Reports

Interval: 1 s

Source: Prepared by the authors using AVEVA Process Simulation software.

When exporting data, the process's controlled variable (*PV*) must be scaled between 0 and 1 ($PV_{scaled,k}$) using Equation 1.

$$PV_{scaled,k} = \frac{PV_k - PV_{hi}}{PV_{hi} - PV_{lo}} = \frac{PV_k - 60000}{60000 - 0}$$

(1)

This scaling is necessary because the error calculation (E) in the simulator's PID control is based on the scaled PV value, both for direct action (Equation 2) and reverse action (Equation 3).

$$E_{direct} = PV_{scaled} - SP_{scaled,k}$$

(2)

$$E_{reverse} = SP_{scaled} - PV_{scaled,k}$$

(3)

Where PV_k is the *PV* value at time step *k*, PV_{min} and PV_{max} are the minimum and maximum values that *PV* can be taken. These values are available in the controller settings tab (Figure 5a).

In the estimation of the FOPTD transfer function, three parameters must be determined: the process gain (K_p); the process time constant (τ_p), and the delay (θ)

(Equation 4). The delay was assumed θ = 0. for this system, as many model-based tuning methods require this parameter.

$$G_p(s) = \frac{PV(s)}{OP(s)} = \frac{1.06}{6s+1} e^{-0.1s}$$

(4)

This transfer function describes the behavior of PV in response to a change in OP. The values of these parameters may vary slightly depending on the method used by the student to estimate the model.

step 2: calculating new tuning parameters for pid control

The AMIGO method (ASTROM; HAGGLUND, 2006) is applied to estimate the new constants of the FC1 controller for the PI controller in FOPTD processes (Equations 5 and 6).

$$K_c = \frac{0.15}{K_p} + \left(0.35 - \frac{\theta\tau_p}{\left(\theta+\tau_p\right)^2}\right)\frac{\tau_p}{K_p\theta}$$

(5)

$$\tau_I = 0.35\theta + \frac{13\theta\tau^2}{\tau_p{}^2+12\theta\tau_p+7\theta^2}$$

(6)

Where K_c, τ_I and τ_D are the parameters of the controller's Proportional, Integral, and Derivative actions, respectively. For this example, the obtained constants are K_c = 19.02, τ_I = 1.11 s and τ_D = 0 s. At this stage, other tuning methods can also be used, such as the IMC method, the ITAE method, or the Ziegler-Nichols Step-Test method (SEBORG, 2010). Once the tuning parameters are determined, the controller's performance can be evaluated.

step 3: analyzing the performance of the new pid controller parameters

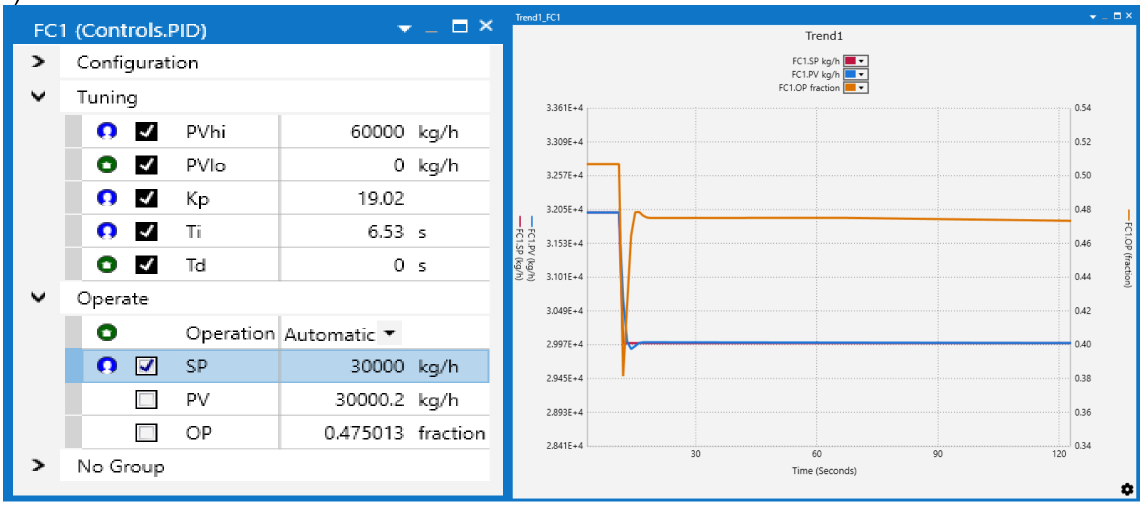
To evaluate the controller's performance, the control mode is first set back to "automatic." Next, the SP is changed to 32,000, and the process is simulated until it reaches a steady state. The simulation is then paused, and a "Snapshot" is recorded by clicking the highlighted icon in Figure X. Saving a Snapshot allows returning to the same process state later, enabling the analysis of different controller constants under identical conditions.

Figure 7. Window for saving the Snapshot.

Source: Prepared by the authors using AVEVA Process Simulation software.

Under these simulation conditions, it is observed that the process manipulated variable (OP) oscillates within a range below 2% of its maximum value. Thus, it can be considered to be in a steady state. From this point, the set point (SP) is adjusted from 32,000 kg/h to 30,000 kg/h, and the simulation is restarted to generate new data (Figure 8). The data is then exported again to an Excel file.

Figure 8. (a) FC1 control configuration and parameters. (b) Trend showing PV (blue), SP (red), and OP (orange) over time.



FC1 (Controls.PID)

Configuration

Tuning

☑ PVhi	60000	kg/h
☑ PVlo	0	kg/h
☑ Kp	19.02	
☑ Ti	6.53	s
☑ Td	0	s

Operate

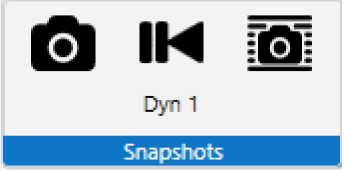
Operation	Automatic	
☑ SP	30000	kg/h
☐ PV	30000.2	kg/h
☐ OP	0.475013	fraction

No Group

Source: Prepared by the authors using AVEVA Process Simulation software.

The process must be returned to its state before the simulation to analyze different controller constants. To do this, click the button highlighted in Figure 9.

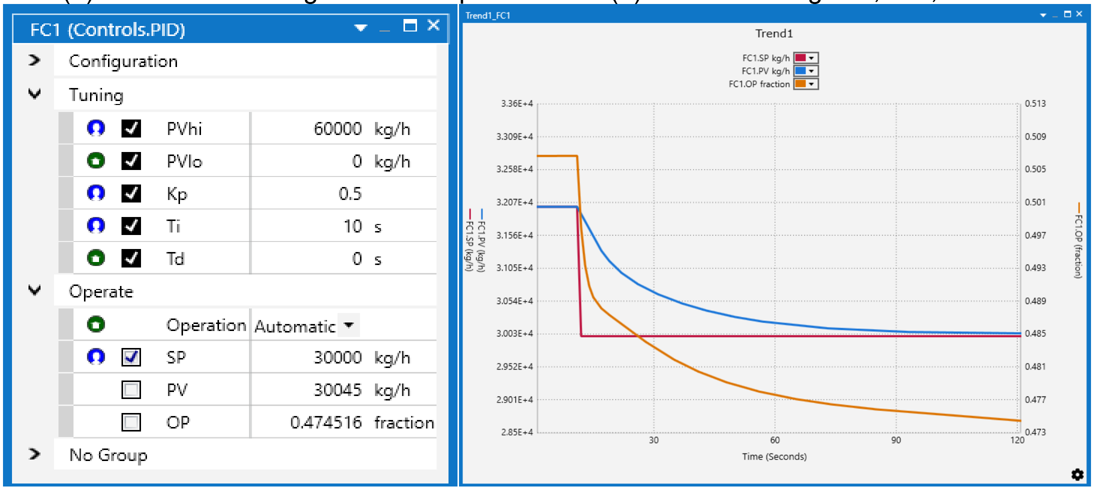
Figure 9. Revert the snapshot to the previous state.



Source: Prepared by the authors using AVEVA Process Simulation software.

Now replace the values in the PID controller with the system's initial parameters: K_c = 0.5, τ_I = 10 and τ_D = 0. Simulate the system for approximately 10 seconds, then change the SP from 32,000 to 30,000 kg/h again. Wait for the system to reach a steady state and export the data (Figure 10).

Figure 10. (a) FC1 control configuration and parameters. (b) Trend showing PV , SP , and OP over time.


FC1 (Controls.PID)

- Configuration
- Tuning
  - ☑ PVhi 60000 kg/h
  - ☑ PVlo 0 kg/h
  - ☑ Kp 0.5
  - ☑ Ti 10 s
  - ☑ Td 0 s
- Operate
  - Operation Automatic
  - ☑ SP 30000 kg/h
  - ☐ PV 30045 kg/h
  - ☐ OP 0.474516 fraction
- No Group

Source: Prepared by the authors using AVEVA Process Simulation software.

Students evaluate the controller's performance using parameters such as settling time, Integral of Absolute Error (IAE), and determining which of the two responses exhibits a smoother control action. Settling Time is required for the process variable (PV) to remain within a specific percentage (e.g., 2% or 5%) of the final steady-state value after a disturbance or setpoint change. It indicates how quickly the system stabilizes.

The IAE is calculated by integrating the absolute value of the error E(t) over time t (equation 7).

$$IAE = \int_0^T |E(t)|\, dt \tag{7}$$

The IAE measures the total accumulated error, giving insight into the controller's overall performance. This same analysis is performed for all other controllers in the simulation. Since each controller has a different response time, the Timespan (X-axis range) must be adjusted to ensure the entire transient response of the process is visible on the generated graph. Proper scaling is essential to accurately observe and compare the dynamics and performance of each controller. By analyzing these metrics, students can better understand the trade-offs between response speed and smoothness in control actions and evaluate the effectiveness of different tuning methods.

EVALUATION OF THE CASE STUDY'S IMPACT

The pedagogical impact of the case study was assessed through a structured questionnaire administered to the students. The questionnaire included quantitative and qualitative questions designed to evaluate their understanding of the theoretical concepts, the effectiveness of the simulation software in bridging theory and practice, and their progression in cognitive skills as outlined by Bloom's Taxonomy (BLOOM et al., 1956). Additionally, the survey gathered feedback on the overall experience, challenges encountered, and suggestions for improvement, providing a comprehensive analysis of the educational outcomes and the students' perceptions of the activity. Each of these statements is assessed using a 5-point scale to evaluate the level of agreement.

RESULTS AND DISCUSSION

At the conclusion of the case study, six students completed a questionnaire consisting of nine questions aimed at evaluating their individual perceptions of the activity. The responses for each question were rated on a 5-point scale, and the average score for each question was calculated Table 1.

Table 1. Average scores of students' responses to the questionnaire evaluating individual perceptions of the case study activity, based on a 5-point scale.

Question	Score
1 - Did the activity contribute to enhancing your understanding of the practical application of process control theory?	4.83
2 - Do you feel confident in tuning a PID controller after completing this activity? (1 Not Confident at All – 5 Very Confident)	4.17
3 - Did the simulation provide clear insights into how changes in control parameters (P, I, D) affect system performance?	4.5
4 - How relevant do you consider this case study for your education in process control? (1 Not Relevant at All – 5 Very Relevant)	4.5

5 - Are you able to identify the main process variables and understand how they influence the system's dynamic response? (1 Disagree – 5 Strongly Agree)	4.5
6 - Was the use of AVEVA Process Simulation helpful in improving your understanding of the dynamic behavior of the controlled system? (1 Strongly Disagree – 5 Strongly Agree)	5
7 - Were the interface and tools of the AVEVA Process Simulation software intuitive and easy to use? (1 Strongly Disagree – 5 Strongly Agree)	4.17
8 - Are you able to propose a dynamic evaluation for other processes in the manufacturing industry? (1 Strongly Disagree – 5 Strongly Agree)	4.17
9 - How satisfied are you with the methodological approach adopted in the case study? (1 Very Dissatisfied – 5 Very Satisfied)	4.48

Source: Prepared by the authors.

According to the case study activity, based on a 5-point scale, the following observations can be made based on the results presented in Table 1:

- Students reported an enhanced understanding of the content learned thus far and expressed satisfaction with the case study.
- The simulator significantly contributed to improving students' comprehension of the theoretical concepts previously studied.
- Students were able to bridge the gap between theory and practice by applying their knowledge to the tuning of controllers.

Overall, the case study effectively enhanced students' understanding of process dynamics and control. Performance evaluations demonstrated reduced settling times and minimized IAE, reflecting improved controller performance with optimized parameters. Feedback from structured questionnaires underscored the following key points:

- Enhanced comprehension of PID tuning.
- Improved confidence in applying control theory.
- Positive perceptions of AVEVA Process Simulation’s interface and functionality.

These outcomes align with the cognitive goals outlined in Bloom’s Taxonomy, promoting higher-order thinking skills such as analysis and evaluation. Based on the experience gained from implementing this case study and the students' feedback, an improvement to the methodology could involve presenting the instructional content through video lessons. During in-person sessions, students would then replicate the procedure for other controllers. This approach addresses the challenges they faced during their initial interaction with the software and optimizes classroom time for more effective learning.

CONCLUSION

Implementing the ethanol-water separation case study using AVEVA Process Simulation had a significant positive impact on the students' cognitive levels and learning outcomes. The activity successfully bridged the gap between abstract concepts and real-world scenarios by progressing from theoretical knowledge to practical application and analysis. Students demonstrated an enhanced understanding of process control principles, improved confidence in tuning PID controllers, and a deeper grasp of how system variables influence dynamic behavior. Furthermore, integrating simulation tools fostered critical thinking and analytical skills, aligning with the higher-order cognitive objectives outlined in Bloom's Taxonomy. This study highlights the value of incorporating dynamic simulations into engineering education to promote active learning, engagement, and skill development, ultimately preparing students for the challenges of modern process control.

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