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# Design of PID Control Strategies of Cylindrical and Conical Tanks

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**Abstract:** *This project focuses on the development and implementation of high-performance PID control strategies for cylindrical and conical tank systems. The main goal is to regulate the liquid level within a set range using a controller based on a First Order Plus Dead Time (FOPDT) model. The control strategies are evaluated using key time-domain parameters such as rise time, peak time, settling time, steady-state error, and overshoot. Various PID tuning techniques—including Ziegler-Nichols, Chien-Hrones-Reswick (CHR), and Cohen-Coon—are applied and compared. The study also highlights limitations of traditional PID tuning methods like Ziegler-Nichols, especially in achieving optimal performance in nonlinear systems..*

**Keywords:** PID control, FOPDT model, level control, Ziegler-Nichols, CHR, Cohen-Coon, time-domain analysis.

## I. INTRODUCTION

The continuous growth of the process industry has significantly increased the demand for better product quality, enhanced operational efficiency, and quicker adaptability to changing market needs. These demands have intensified the need for effective control strategies. Among various control approaches, the Proportional- Integral-Derivative (PID) controller remains a cornerstone in industrial automation due to its simplicity, robustness, and practical applicability.

A PID controller works by calculating the error between a desired setpoint and the current process variable[8]. This error is processed through three control actions—proportional, integral, and derivative—to produce a corrective signal that drives the system toward the desired operating point[4]. The controller's success heavily depends on the tuning of these parameters to ensure desirable system performance, such as minimal overshoot, faster settling time, and good disturbance rejection.In industrial environments, especially in liquid level control systems, PID controllers are widely used because of their ease of implementation and effectiveness[7]. This study specifically focuses on cylindrical and conical tank systems, which are commonly found in storage and mixing processes. While cylindrical tanks have a constant cross-sectional area and are relatively easier to control, conical tanks exhibit nonlinear characteristics due to their varying geometry, posing greater challenges in maintaining stable liquid levels.

To address these challenges, this research explores and compares several popular PID tuning methods: Ziegler-Nichols, CHR (Chien, Hrones, and Reswick), and Cohen- Coon. These methods are applied to both cylindrical and conical tanks, and their performance is analyzed based on key control metrics.

Advanced PID-based approaches are also considered, especially for handling the nonlinear dynamics of conical tanks. Methods like IMC-PID (Internal Model Control), Fuzzy Logic PID, and Fractional Order PID (FOPID) are evaluated for their ability to provide more robust and adaptive control.

The primary goal of this research is to develop dynamic models of these tank systems, apply suitable PID tuning techniques, and evaluate their performance through simulations and hardware implementation.[2] By doing so, the study aims to contribute to improving control efficiency, system stability, and adaptability in complex industrial processes.

## II. METHODS AND MATERIAL

Maintaining liquid levels in storage tanks is a key control problem in industries like chemical processing and water treatment. Cylindrical tanks exhibit near-linear dynamics, but real-world conditions—such as valve characteristics, sensor delays, and varying flow rates—introduce nonlinearities. PID controllers are widely used due to their simplicity, yet classical tuning methods like Ziegler-Nichols often lead to overshoot, slow response, and poor disturbance handling, especially across varying operating conditions. Conical tanks pose greater challenges because their geometry results in a nonlinear relationship between liquid height and volume, causing dynamic behavior to vary with level. This makes control more complex, particularly at low and high levels where system gain and time constants change significantly.

To address these challenges, this project proposes advanced PID strategies for cylindrical and conical tanks. The approach includes mathematical modeling of both tank types, classical and modified PID controller implementation, and simulation using MATLAB/Simulink. Performance will be evaluated based on rise time, settling time, overshoot, steady- state error, and disturbance rejection. A comparative analysis will determine the best-suited control strategy for each geometry. The expected outcome is a set of optimized PID designs and a framework to guide controller selection based on tank shape and system behavior.

**General Procedure:**

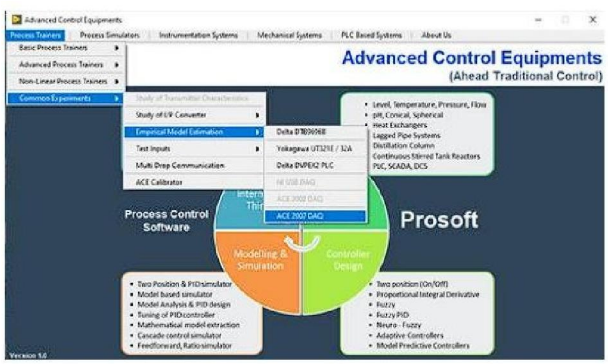
**Hardware:**

- Adjust the valve positions as given above.
- Switch on electric supply. Switch on Mains.
- Switch on Pumps. (b) Conical Tank (d) Triangular Tank
- Adjust the rotameter valve for a flow of 150LPH.
- Adjust the drain valve V11 such that tank level remains at 95 to100%

**Software:**

- Double click "Ace.exe" icon in desktop.
- Select: Basic Process Trainers ---> Empirical

Model Estimation ---> ACE 2007 DAQ




Wait for the GUI to open. The description of the page is shown below.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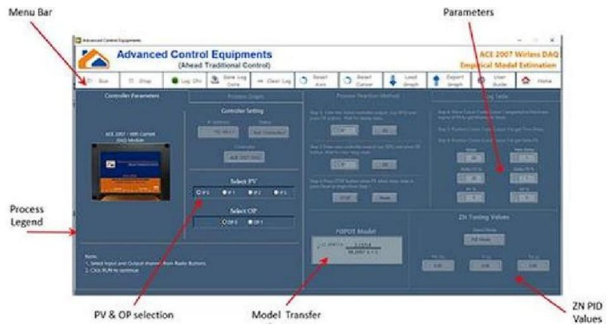
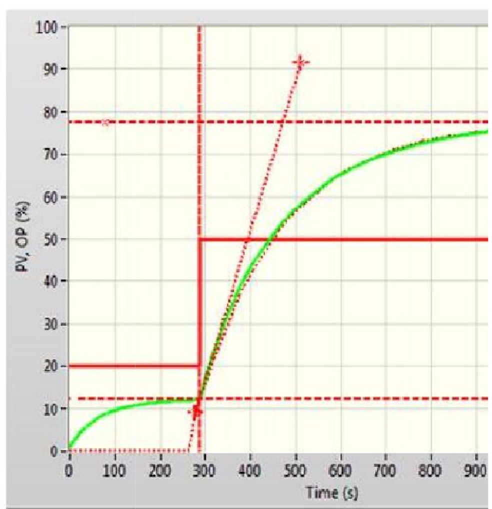



The experiment can be performed by following the instructions on the screen as listed below: Design of PID control strategies for Conical and Cylindrical vessel storage systems. 26 • Select PV as required and OP0. Click 'RUN". • WiFi DAQ will be connected automatically. If not connected, follow the procedure given in Device Connection. • Enter the initial controller output (say 20%) and press OK button. Wait for steady state. (Once if OK button is pressed, 'Process Plot' tab will be enabled. You can also scroll to 'Process Schematic'. Observe the response on the process plot.)

Press 'STOP' if you want to restart at any time. • Once steady state is achieved, enter new controller output (say 50%) and press OK button. Wait for new steady state. • Press STOP button when PV attain steady state. • Once STOP button is pressed, cursors will be enabled in the process plot. • Move Cursor 0 and Cursor 1 tangential to the linear region of PV to get Maximum Slope. • Position Cursor 2 and Cursor 3 to get Time Delay. Use zoom option, if required. • Position Cursor 4 and Cursor 5 to get Delta PV. • The FOPDT model and ZN open loop tuned PID values will be displayed automatically.

A red dotted line represents the response of the model. Adjust cursors 0,1 and 4,5 to get a model close to the actual response.

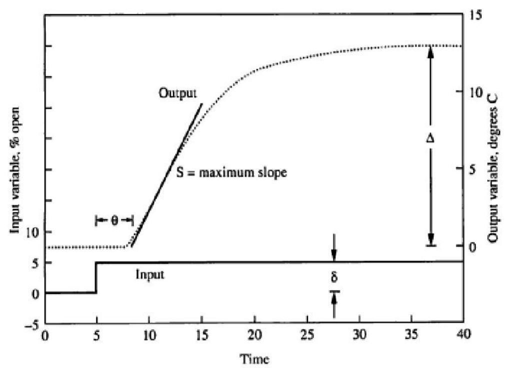
A typical graph is shown below.




Determination of system model Empirical Model: In empirical model building, models are determined by making small changes in the input variable(s) about a nominal operating condition. The resulting dynamic response is used to determine the model. This general procedure is essentially an experimental linearization of the process that is valid for some region about the nominal conditions. The Process Reaction Curve Method: The process reaction curve method involves the following four actions: • Allow the process to reach steady state. • Introduce a single step change in the input variable. • Collect input and output response data until the process again reaches steady state. • Perform the graphical process reaction curve calculations. The graphical calculations determine the parameters for a first-order-with-dead-time model: the process reaction curve is restricted to this model. The form of the model is as follows, with X(s) denoting the input and Y(s) denoting the output, both expressed in deviation variables:

$$\frac{Y(s)}{X(s)} = \frac{K_p e^{-\theta s}}{\tau s + 1}$$

This technique, adapted from Ziegler and Nichols (1942), uses the graphical calculations shown in Figure.




Where,

S - Maximum Slope

Δ - Magnitude of the steady-state change in the output

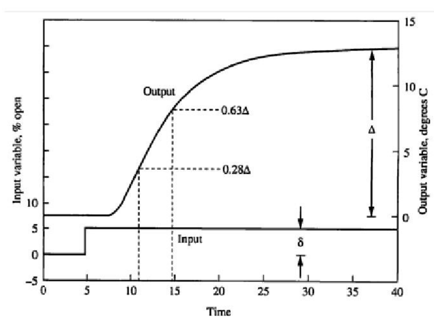
δ - Magnitude of the input change

The model parameters can be calculated as

$K_p = \Delta/\delta$

$\tau = \Delta/S$

Two Point Method: This method uses the graphical calculations shown in Figure. The intermediate values determined from the graph are the magnitude of the input change, δ; the magnitude of the steady-state change in the output, Δ; and the times at which the output reaches 28 and 63 percent of its final value.




The values from the plot can be related to the model parameters using the general expression in equation below. Any two values of time can be selected to determine the unknown parameters, θ and τ. The typical times are selected where the transient response is changing rapidly so that the model parameters can be accurately determined in spite of measurement noise (Smith, 1972). The expressions are

$Y(\theta+\tau) = \Delta(1-e^{-1}) = 0.632\Delta$

$Y(\theta+\tau/3) = \Delta(1-e^{-1/3}) = 0.283\Delta$

The values of time at which the output reaches 28.3 and 63.2 percent of its final value are used to calculate the model parameters.

$t_{(28\%)} = \theta + \tau/3$ $t_{(63\%)} = \theta + \tau$

$t_{(28\%)} = \theta + \tau/3$ $t_{(63\%)} = \theta + \tau$

In order to calculate the output of the PID controller, the three terms are summed together, which can be expressed as formula

$$y(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

The strategy of the method is that first set and to zero while as a small gain, and then gradually increase the value of until the value that caused the oscillation of the control output, record the oscillation period .Then we can adjust the parameters

| Controller type | Step response | | | Frequency response | | |
|---|---|---|---|---|---|---|
| | $K_p$ | $T_i$ | $T_d$ | $K_p$ | $T_i$ | $T_d$ |
| P | $1/a$ | - | - | 0.5 $Kc$ | - | - |
| PI | $0.9/a$ | $3L$ | - | 0.4 $Kc$ | 0.8 $Tc$ | - |
| PID | $1.2/a$ | $2L$ | $1/a$ | 0.6 $Kc$ | 0.5 $Tc$ | 0.2 $Tc$ |

Ziegler-Nichols PID Tuning method
Where =KL/T , and Tc=2π/ωc

| Controller Type | Step response | | | Frequency response | | |
|---|---|---|---|---|---|---|
| | $K_p$ | $T_i$ | $T_d$ | $K_p$ | $T_i$ | $T_d$ |
| P | $0.3/a$ | - | - | $0.7/a$ | - | - |
| PI | $0.6/a$ | $4L$ | - | $0.7/a$ | 2.3 $L$ | - |
| PID | $0.95/a$ | $2.4L$ | $0.42L$ | $1.2/a$ | 2 $L$ | 0.42 $L$ |

CHR Test PID Tuning method
Where a=Kθ/T

| Controller | $K_p$ | $T_i$ | $T_d$ |
|---|---|---|---|
| P | $(1/a)\left(1+\frac{0.35\tau}{1-\tau}\right)$ | - | - |
| PI | $(0.9/a)\left(1+\frac{0.92\tau}{1-\tau}\right)$ | $\left(\frac{3.3-3\tau}{1+1.2\tau}\right)\times L$ | - |
| PID | $(1.35/a)\left(1+\frac{0.18\tau}{1-\tau}\right)$ | $\left(\frac{2.5-2\tau}{1-0.39\tau}\right)\times L$ | $\left(\frac{0.37-0.37\tau}{1-0.81\tau}\right)\times L$ |

Cohen-coon Test PID Tuning method
Where a=KL/T and τ=L/((L+T))

## IV. RESULTS AND DISCUSSION

To evaluate and compare different control strategies for a level control system, simulations were conducted using MATLAB Simulink. The primary focus was on performance metrics such as set point tracking, disturbance rejection, and robustness.

Simulations revealed that although set point tracking performance decreases with model inaccuracies, the overall control remains acceptable. The proposed methods demonstrated better disturbance rejection capabilities. Various parameters like peak overshoot, settling time (time to remain within 2% of the final value), and other quality indicators were analyzed to assess controller performance.

**Simulink Model**

The system was modeled in Simulink using various components. The Signal Generator/Input Block provided test signals such as sine or square waves. Mathematical Operators like Gain and Sum blocks processed the input. Data Conversion Blocks such as Mux, Demux, and data type converters ensured signal compatibility. TCP/IP Send and Receive blocks enabled communication with remote systems for real-time data transfer.

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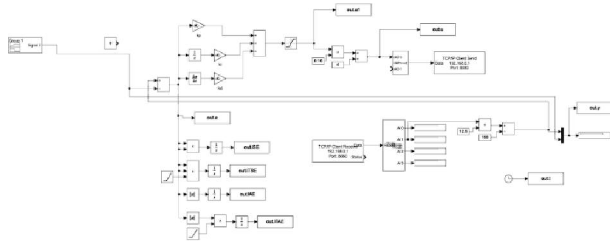
Scopes and Display Blocks were used to visualize and validate output behavior.



The Simulink model simulated the responses of three tuning methods: Ziegler-Nicholes (Z-N), Chien-Hrones-Reswick (CHR), and Cohen-Coon for both cylindrical and conical tanks. Controller parameters (Kp, Ki, Kd) were derived for each method and are listed in Tables

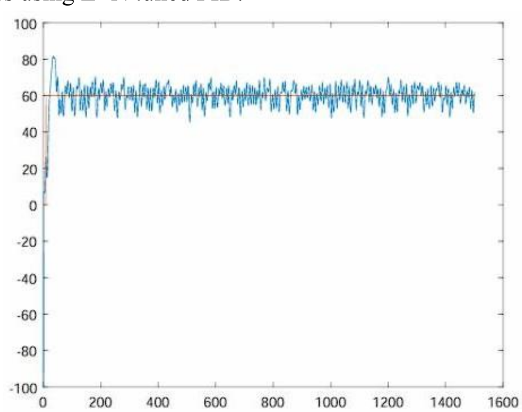
| Controller method | PID Controller | | | | |
|---|---|---|---|---|---|
| | $K_p$ | $T_i$ | $T_d$ | $K_i$ | $K_d$ |
| Z-N Method | 4.8 | 10.45 | 2.6113 | 0.46 | 27.3 |
| CHR Method | 2.4 | 18.3817 | 2.6113 | 0.131 | 6.27 |
| Cohen-coon | 5.68 | 11.771 | 0.49 | 0.483 | 2.783 |

PID tuning parameters for cylindrical tank.

| Controller method | PID Controller | | | | |
|---|---|---|---|---|---|
| | $K_p$ | $T_i$ | $T_d$ | $K_i$ | $K_d$ |
| Z-N Method | 16.67 | 4.6 | 1.15 | 3.62 | 19.171 |
| CHR Method | 8.333 | 83 | 1.15 | 0.1004 | 9.58 |
| Cohen-coon | 18.844 | 5.7 | 0.8342 | 3.31 | 15.72 |

PID tuning parameters for conical tank.

Controller Responses for Cylindrical Tank
Z-N Method: Graph 1 and 2 show
nominal and disturbance responses using Z- N tuned PID.




Graph 1: Nominal response for cylindrical tank using Z-N Method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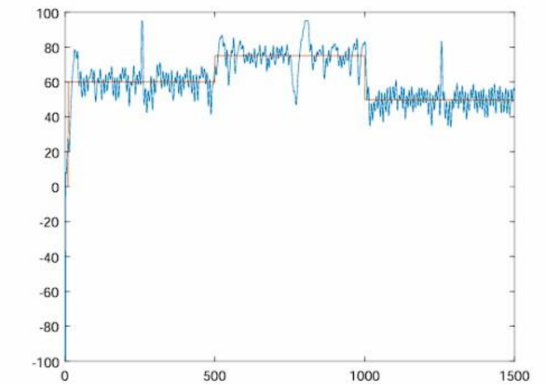
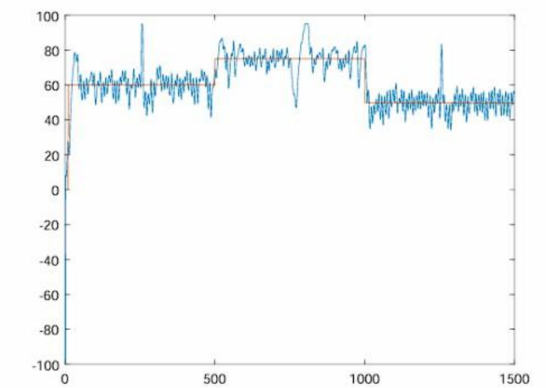
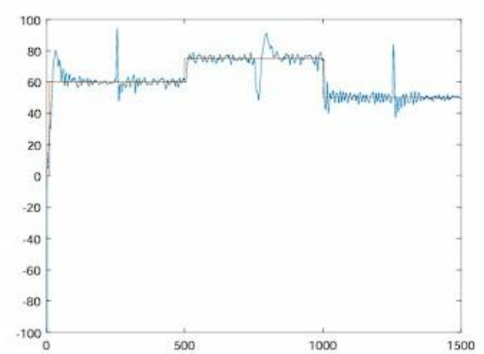


Graph 2: Disturbance response for cylindrical tank using Z-N Method

CHR Method: Graphs 3 and 4 display the CHR responses, showing better control performance.



Graph 3: Nominal response for cylindrical tank using CHR Method



Graph 4: Disturbance response for cylindrical tank using CHR Method

Cohen-Coon Method: Graphs 5 and 6 show responses with moderate overshoot and good settling time.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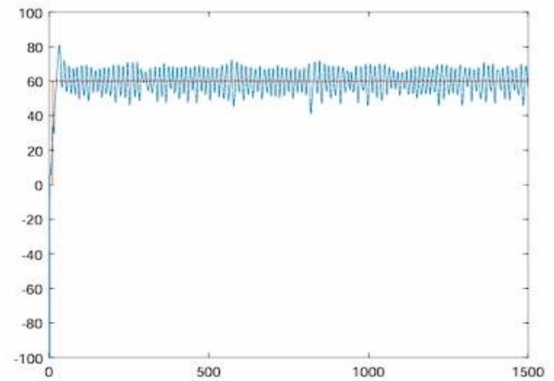
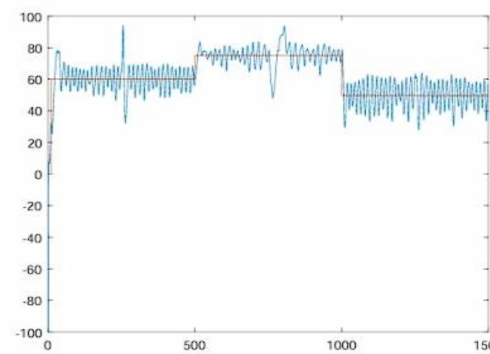



Graph 5: Nominal response for cylindrical tank using Cohen Coon Method




Graph 6: Disturbance response for cylindrical tank using Cohen Coon Method

A comparison table revealed that CHR tuning provided the least peak overshoot (70.91%) and a reasonable settling time (74s), compared to Z-N (81.58%, 75s) and Cohen-Coon (80.80%, 60s), indicating CHR's better performance in minimizing overshoot.

**Controller Responses for Conical Tank**

Various PID tuning methods can be applied to control a conical tank system, each offering distinct advantages in terms of stability, responsiveness, and performance. The Ziegler-Nichols (Z-N) Method provides a systematic approach for tuning, typically resulting in an aggressive controller with fast response but possible overshoot. The Chien-Hrones-Reswick (CHR) Method aims to balance performance and stability, often yielding a more stable system with reduced oscillations. The Cohen- Coon Method is particularly effective for systems with time delays, offering fast settling times with minimal steady-state error, though it may introduce slight overshoot. By analyzing the characteristics and outcomes of each method, one can choose the most appropriate tuning strategy based on the conical tank's nonlinear dynamics and the desired control objectives.

## V. CONCLUSION

We get better performance of CHR PID Controller on the basis of settling time, peak overshoot, peak time, steady state error and rise time as compared to Z-N PID Controller and Cohen-coon PID Controller. For the nonlinear plant when dynamics of plant is changed, or there is an uncertainty this PID gives better response. It also gives better disturbance rejection. PID controller can adjust the control action before a change in the output set point actually occurs. Hence from the results we conclude that CHR PID control strategy is better than all other PID controller strategies

## REFERENCES

**[1].** J.G. Ziegler and Nichols, “Optimal Settings for Automatic Controllers”, Trans. ASME, vol. 64 P.P. 759-768, 1942.

**[2].** K.J. Astrom and T. Haughland, “Automatic Tuning of PID Controllers”, 1st ed. Research Triangle Park, NC: Instrum.Soc. Amer, 1988.

**[3].** K.J. Astrom and T. Haughland, “Automatic Tuning of PID Controllers”, 1st ed. Research Triangle Park NC: Instrum.Soc. Amer, 1995.

**[4].** Vikas Karade, Ambadas Shinde, Sagar Sutar, “Design and Implementation of PID Controller for Single Capacity Tank”, Vol. 5, Issue 11, IJIRSET, November 2016.

**[5].** C. V. Nageswara Rao a, A. Seshagiri Raob, and R. Padma Sree, “Design of PID Controllers for Pure Integrator Systems with Time Delay”, IJASE, 2011. 9, 4: 241-260

**[6].** Dr.G.Saravanakumar, Dinesh.S, Preteep.S, Sridhar.P and Suresh.M, “Controller Tuning Method for Non-Linear Conical Tank System”, AJAST, Volume 1, Issue 2, Pages 224-228, March 2017

**[7].** Astrom K., Hagglund T., “PID controllers: theory, design and tuning”, USA: Instrument Society of America; 1995.

**[8].** Q.-G. Wang, “ PID tuning with exact gain and phase margins”, ISA Transactions, 38 (1999), pp. 243-249

**[9].** Pingkang Li, Peng Wang, Xiuxia, “ An approach to optimal design of stabilizing PID controllers for Time-delay systems”, IEEE (CCDC 2009), pp. 3645-3470, 2009

**[10].** V. Selvi Sowmya, S. Priya dharsini, R.Priya Dharshini, P. Aravind, “Application of various PID Controller Tuning Techniques for a Temperature System”, International Journal of Computer Applications (0975 – 8887) Volume 103 – No.14, October 2014