Design and optimization of digitalization device of temperature control system using PID Ziegler-Nichols control in chemical engineering laboratory

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Abstract. The Temperature Control Module is a tool that is useful for adjusting the temperature of a liquid or solution so that the temperature of a liquid is as determined. A device that uses a heat exchanger as a place to combine temperature, so that the temperature of a liquid with another liquid will meet there so that the temperature of the liquid in the heat exchanger can be changed. From the temperature control practicum module prototype in the chemical laboratory, it is known that in the open loop test with hot water input temperature above 90 °C and cold water input temperature 28 °C an output value of 69 °C is obtained. This value is stable but slowly decreases. By providing feedback and the controller in the form of sensors and data will be processed by the PLC, then a value that corresponds to a set of values is obtained, namely 60 °C, but the output temperature is unstable because the output graph is still fluctuating and unstable. Based on experimental calculations and PID calculations using the Ziegler Nichols method, the Kp = 30, Ti = 77.95, and Td = 19.489 were obtained. By providing the PID algorithm calculated by the Ziegler Nichols method, it can increase the output temperature to 58 °C. This is due to the addition of the PID gain to be more substantial so that the system becomes unstable.

1. Introduction

The electric power control system is used as a remote control. Arrangements are usually made in the SCADA control room. Many things can be controlled in the field of learning such as motors, valves and other electrical equipment. One example of the use of control systems in field learning is found in the Chemistry Laboratory of State Polytechnic of Malang AQ in the student practicum module. Examples of practicum modules are pH control, valve control, temperature control and others. The practicum module is very important because it supports the learning process and trains students' skills.

The problem in the practicum module is that the practicum module used by practicum students is damaged so that teachers and students cannot use the module and interfere with the learning process. Proportional Integral Derivative (PID) is a feedback mechanism controller that is usually used in industrial control systems. Output the PID controller is the sum of the outputs proportional controller, integral controller output. The characteristics of the PID controller are strongly influenced by the large contribution of the three parameters P, I and D [1]. In the Temperature Control prototype module you can use PID to calculate the error value as the difference between the desired set point and the measured process variable so that by determining the PID value the error value can be reduced.
2. Literature review

2.1. Heat transfer and flow rate

2.1.1. Energy balance. The flow in the gap is completely closed, so that the energy equilibrium can be used to determine the varying fluid temperature and the total value of convection heat transfer $Q_{\text{conv}}$ depending on the mass flow rate [2]. If the changes in kinetic energy and potential energy are neglected, then the changes in heat energy and working fluid will have a significant effect. So that the energy balance depends on 3 variables, which can be formulated as follows [3-6].

$$Q = m_c \cdot C_{p,c} \cdot \Delta T_c = m_h \cdot C_{p,h} \cdot \Delta T_h$$  \hspace{1cm} (1)

$Q$ = heat transfer rate (W)

$m_c$ = mass flow through the tube (kg / s)

$m_h$ = mass flow through the shell (kg / s)

$C_p$ = coefficient of heat transfer (KJ / kg.K)

$\Delta T_c$ = temperature difference of cold fluid through the tube (oC)

$\Delta T_h$ = temperature difference of hot fluid through the shell (oC)

2.2. Control system

A control system is the process of regulating or controlling one or several plants to be within a certain price range. A factory in a control system is a set of equipment that may consist of only a few parts of a machine that work together, which are used to carry out a certain operation. In the application of the control system there is also interference in the form of signals that tend to have a detrimental effect on the system output price.

2.2.1. PID Ziegler Nichols. To get the appropriate PID value used several methods, including the Auto Tuning method on MATLAB software, Ziegler Nichols method and try and error method [7,8]. In previous studies, it was found that the fastest response to show temperature stability was the Ziegler and Nichols method [9]. Ziegler and Nichols suggest setting the $K_p$, $T_i$ and $T_d$ parameter values based on the formula shown in Table 1.

Table 1. Ziegler Nichols adjustment rules based on strengthening the $K_{cr}$ and the critical $P_{cr}$ period (Second method).

| Control Type | $K_p$        | $T_i$    | $T_d$     |
|--------------|--------------|----------|-----------|
| P.           | 0.5 $K_{cr}$ | ~        | 0         |
| PI           | 0.45 $K_{cr}$ | $\frac{1}{1.2}P_{cr}$ | 0         |
| PID          | 0.6 $K_{cr}$ | 0.5 $P_{cr}$ | 0.125 $r$ |

3. Methodology

3.1. Time and place of research
The research site is in the Control System Laboratory and Laboratory of Chemical Engineering in the State Polytechnic of Malang. The time of this research takes place in December 2019 to May 2020.

3.2. Object of research
In the process of working on this thesis, the object of research is the change in temperature at the valve output under uncontrolled or open loop conditions, valve control with PID and without PID.
3.3. Temperature control prototype testing flow chart

![Flow chart of temperature control prototype testing](image)

**Figure 1.** Temperature control prototype testing flow chart.

4. Discussion

4.1. Input, process, output parameters on temperature control

4.1.1. Input parameters. The component for input to Temperature Control is Thermocouple. So the parameter on the input component is temperature, the temperature will be detected by a thermocouple and then it will be converted to voltage so that it can be processed on the PLC. Values read on the PLC range from 0 to 5000. Input temperature used for hot water input is 90 °C and cold water temperature is around 28 °C if according to equation 2.1 a value of 59 °C is obtained for the output temperature if it is assumed that the mass and heat values considered 1.

4.1.2. Process parameters. The process component of Temperature Control is the Programmable Logic Controller (PLC), which is used as control of this prototype. PLC accepts the value of the input which is in the form of voltage and then used as decimal or hexadecimal numbers. This value will be processed using a ladder program. The value that is in the PLC can be sent in the form of current or voltage to activate the output according to user wiring [10].

4.1.3. Output parameters. The output component in the Temperature Control is a control valve, the valve is controlled by the voltage generated by the PLC, the signal voltage rating is 0-10V, the
greater the voltage sent by the PLC, the greater the hole that is opened by this valve. For output components in the form of relays only logic 1 and 0 which means on or off, the PLC will send a signal in the form of a voltage to make the relay active on the digital output. This relay is useful for activating pumps that require a 220V supply so that relay contacts are needed so that the pump can be activated and controlled by a PLC.

4.2. Analysis of open loop, close loop and close loop testing using PID in the temperature control prototype

4.2.1. Open loop temperature control experiment analysis

Based on Figure 2, the heat temperature used as input in the heat exchanger will continue to decrease from the original 94 °C to 83 °C. The temperature of the cold water input is initially 26 °C but after entering the heat exchanger the temperature will change to 60 °C. When the hot temperature for the input is valued at 90 °C, it can change the temperature of the cold water that was originally 28 °C to a temperature of 69 °C can even be 70 °C. The peak time needed to reach the peak value from the first overshoot is 3 minutes. The maximum peak value (maximum overshoot) is 69.2 °C, if formulated in a percentage of 6.3%. ESS of open loop testing i.e. 13.3%.

4.2.2. Close loop trial analysis without PID. Based on Figure 3 the temperature experiment data graph above the time needed to rise to reach the final value of the response which is about 1 minute (rise time). The peak time needed to reach the peak value from the first overshoot is 3 minutes. The maximum peak value (maximum overshoot) is 61.3 °C, if formulated in a percentage of 2.83%. ESS from close loop testing without PID which is 5%.
4.2.3. **Close loop testing analysis using PID**

**Figure 4.** Graph of output close loop output using PID.

**Figure 5.** Test graph open loop, close loop without PID, close loop using PID.

Based on the experimental data chart table, the temperature of 30 °C will rise to near set value. The output temperature will be stable at 58 °C, using PID the output temperature cannot reach the set value that is 60 °C. Based on the table graph of temperature experiment data above the time needed to rise to reach the final value of the response which is about 2 minutes (rise time). ESS from close loop testing using PID which is 2.3%.

4.2.4. **Graph analysis of open loop trial, close loop without PID, close loop using PID.** Based on Figure 5, during the open loop experiment the output temperature will continue to rise to a temperature of 69.2 °C. When the close loop experiment without PID, the temperature fluctuates so that it exceeds the setpoint value of 61.3 °C. By using a PID system (with PID), the system becomes better because the resulting output temperature is more stable in the range of 58 °C with the specified setpoint is 60 °C, not only that if the system is given a PID, the steady state error is smaller than the other experiment is 2.3%. If the system is not given a PID (without PID) configuration, the output value can exceed the setpoint of 61.3 °C or experience an overshoot of 2.83%. When the system is given a PID, the output value is stable close to the setpoint value and does not experience overshoot. The time to output reaches a 60 °C setpoint value is almost the same, that is, it takes about 3 to 4 minutes to reach the 60 °C setpoint.

4.3. **PID tuning with the Ziegler Nichols method**

To determine the value of PID in a system whose equation is unknown, testing is needed to get the value of the equation in the system then a multiple method approach is used to obtain the appropriate PID value. Tests carried out on a prototype system Temperature Control by providing a variable temperature input then see the response from the heat exchanger output. Here are the results of calculating the PID value based on testing.

- \( K_p = 0.02418 \)
- \( K_i = 0.0031 \)
- \( K_d = 0.0124 \)

Adding the \( K_p \) value to 30 makes the system more stable.
Figure 6. Response graph using the Ziegler Nichols method before and after the addition of Kp 30.

5. Conclusion

Based on the formulation of the problem in research, it can be concluded that:

The Temperature Control prototype consists of input, control, and output components, each component has a parameter, for the input component that is changing the temperature to DC voltage, then the voltage is processed into hexadecimal or decimal numbers so that it can be processed by the PLC, after the number is processed then the number The DC voltage will be made again by 0-10 V so that it can be used to activate the PLC output. The temperature value of the heat exchanger temperature is calculated based on 59 °C using hot water input temperature of 90 °C and cold water of 28 °C.

Based on experimental calculations and PID calculations using the Ziegler Nichols method, the values of Kp = 30 Ti = 77.95 and Td = 19.448 were obtained. By entering the PID value, the system will run more stable than not using the PID algorithm.

Based on the three experiments, namely Open Loop, Close Loop without PID, Close Loop with PID, the output results obtained are as follows:

- When the Open Loop test uses hot water input temperatures of 90 °C and cold water input temperatures of 28 °C, an output value of 69 °C is obtained, this value exceeds the setpoint of 60 °C, with a time of about 4 minutes. mthe output temperature is overshooted by 6.3%. In addition, the Steady State Error value is also large at 13.3%.
- When testing the Close Loop without PID using a hot water input temperature of 90 °C and cold water input temperature of 28 °C, an output value of up to 60 °C is obtained, this value has reached a setpoint of 60 °C but the temperature is still less stable due to an increase temperature so that it experiences an overshoot of 2.83%. In addition the value of Steady State Error is also large at 5%.
- When testing the Close Loop using PID using a hot water input temperature of 90 °C and cold water input temperature of 28 °C, an output value of 58 °C is obtained. Steady State error when using PID is 2.3%, and does not experience overshoot like an experiment without PID.
- If giving a PID to the system will make the system more stable, reduce Steady State Error by 2.7% and also eliminate overshoot.

The SCADA design on the Temperature Control prototype was created using Cx-Supervisor software. In this SCADA there are several menus such as monitoring that function to monitor which components are active and also see the temperature in the system. Apart from SCADA monitoring, it also has a controller feature that functions to run programs, enable or disable pumps and PID configuration. There is also a trend graph that functions to see the increase or decrease in temperature in the system and there is a menu for storing temperature data so that the data will be stored in Microsoft Excel in the form of a table.

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