Process Control for System Temperature

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Abstract

Process control is crucial in the operations of chemical engineering plants and manufacturing processes across a broad range of industries. This report details the testing and optimization of P, PI, PID controllers for a temperature control system. The first objective is to determine the best controller type for controlling the system temperature. The second objective is to alter tuning parameters manually for PID controllers in the temperature control system to achieve optimality. The performance criteria include the settling time, peak-to-trough ratio, and steady state offset. It is discovered that PID controller is the best due to its fast response, offset elimination, and minimized settling time and oscillations, combining the aspects of Proportional (P), Integral (I), and Derivative (D) control. Additionally, manual tuning attempts were made to fine-tune the PID controller. However, the lack of data points lead to inconclusive results. Future works should conduct additional trials or employ alternative tuning methods.

Background and Theory

- Used in steam engine to control fuel intake to engine with the centrifugal speed governor, which helped control the speed of the train or car
- One of the reasons for the Chernobyl disaster was due to poor process control. The safety mechanism to slow down the reactor eventually led to the reactor to blowing up due to scenarios that weren't accounted for by the reactor plant designer

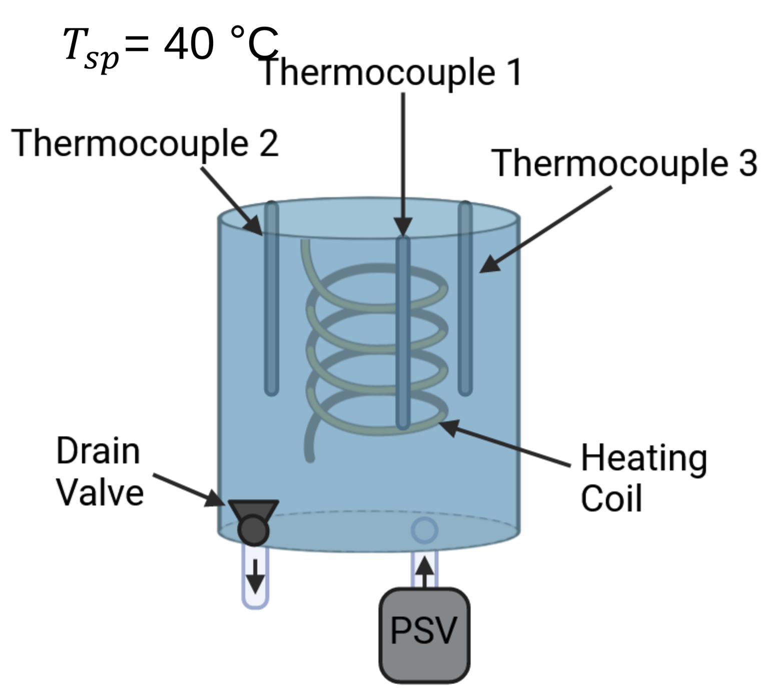
- Objective of process control is to reduce error signal to zero, such that the measured variable is equal to the set-point

$$e(t) = y_{sp}(t) - y_m(t)$$

- Governing equation of PID controller incorporates proportional, integral, and derivative controller

$$p(t)=\bar{p} + K_c(e(t) + \frac{1}{\tau_I}\int_0^t e(t^*)dt^* + \tau_D\frac{de(t)}{dt}) \qquad [1]$$

Materials and Methods



Temperature control system consists of:

- Heating coil
- Drain valve
- Control valve (PSV)
- Three Thermocouples

P Control:

- Proportional band = 100 %
- 8 mins trial

PI Control:

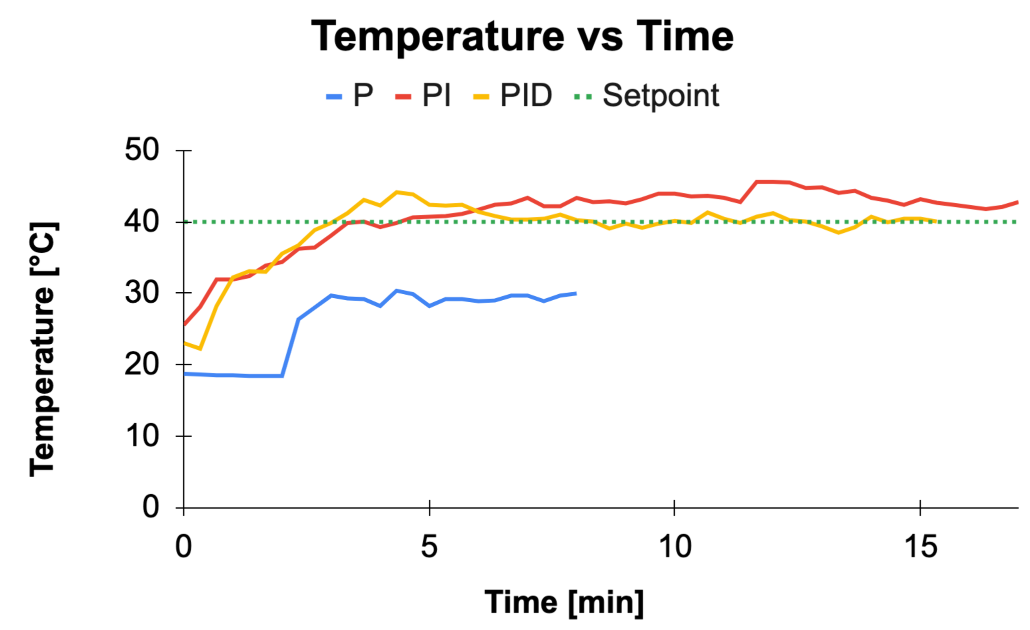
- Proportional band = 200 %
- Integral time = 60 s
- 17 mins trial

PID Control: Start with PI settings, tune based on response

Results and Discussion

Determination of Best Controller Type

P Control			PI Control			PID Control		
Settling Time	Peak-to-Trough Ratio	Steady State Offset	Settling Time	Peak-to-Trough Ratio	Steady State Offset	Settling Time	Peak-to-Trough Ratio	Steady State Offset
5 m 19 s	N/A	10.7 °C	>10 m	1.16	2.8 °C	8 m 19 s	1.14	0.7 °C



Performance Criteria:

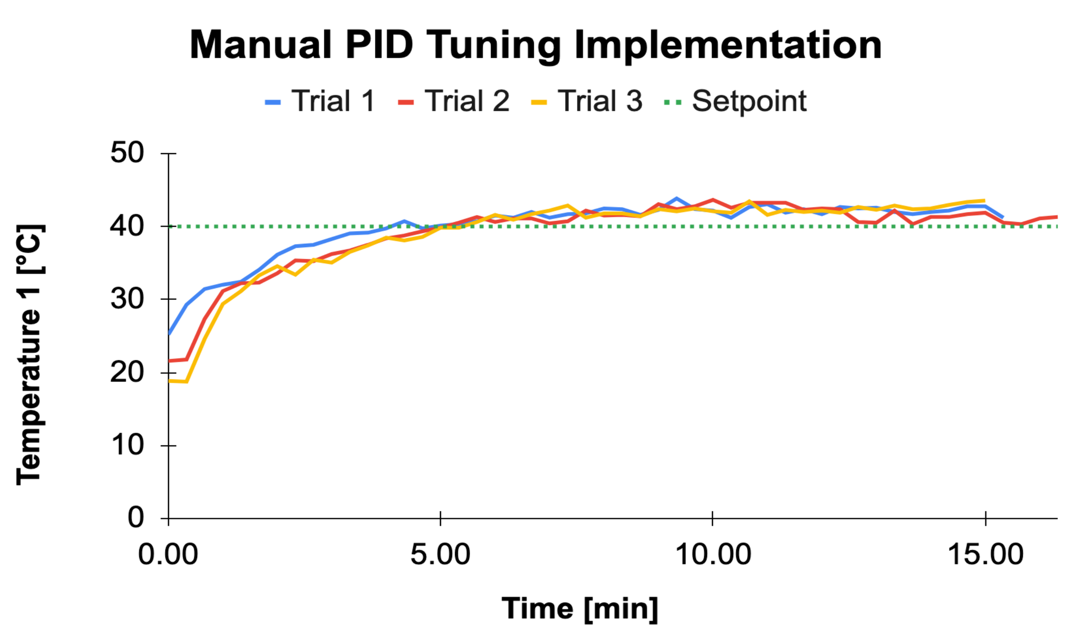
- **Settling Time:** Amount of time to reach steady state
- **Peak-to-trough Ratio:** Ratio of Overshoot to Undershoot
- **Steady State Offset:**

$$|T_{sp} - T_{actual}|$$

Manual Tuning for PID Controller

Trial #	Steady-State Offset (°C)	Settling Time (m,s)	Peak-to-Trough Ratio
1	1.9	11 m, 20 s	1.103
2	1.7	14 m, 40 s	1.097
3	2.2	7 m, 00 s	1.095

Setpoint: 40 °C			
Trial #	P%	I	D
1	170	40	8
2	170	45	8
3	170	50	10



Error Analysis:

- Apparatus lifetime and calibration unknown
- Investigate more criteria, such as robustness or noise sensitivity
- Decrease tuning complexity by manipulating one parameter at a time

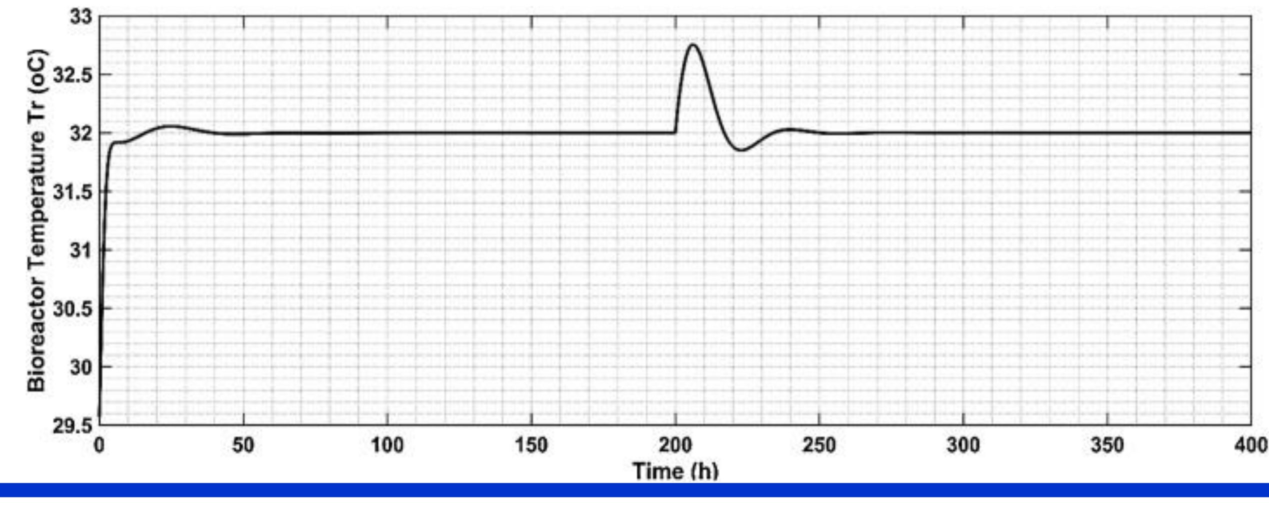
Design Extension

How do you produce quality alcohol?

Temperature control is extremely important in maximizing ethanol production and eliminating deadly by-products such as methanol, which can cause blindness and death. Parasitic side reactions can occur outside of temperature range, and ethanol yield will be reduced.

Fermenter Design:

- Ideal Setpoint range of 30 – 35 °C, Setpoint of 32 °C was used
- Fermenter batch cycle of 50 – 60 hours
- Must maintain setpoint temperature despite inevitable disturbances in process
- Requires minimal steady state offset and settling time
  - PID control is optimal for these requirements



[2]

Conclusion

The results suggest that PID controller is the best for temperature control due to its moderate response time, minimal offset, and smallest peak-to-trough ratio. Upon fine-tuning the PID controller using manual tuning method, the lack of sufficient data prevent us from drawing a definitive conclusion. Error in the experiment can arise from the unknown lifetime/calibration of the system, the lack of other criteria for performance determination, and tuning complexity. Future works should include more trials to fine-tune the PID controller or employ alternative tuning methods such as impulse tuning or Ziegler-Nicholas (Z-N) tuning methods.

References

[1] D. E. Seborg, Process dynamics and control, Fourth edition, 2017.
[2] M. Kumar, D. Prasad, B. S. Giri, and R. S. Singh, "Temperature control of fermentation bioreactor for ethanol production using IMC-PID controller," Biotechnol Rep (Amst), vol. 22, p. e00319, Feb. 2019, doi: 10.1016/j.btre.2019.e00319.

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