

1809797

by Lourens Brits

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1. Executive Summary

Research was carried out into flow, level and temperature control systems. It was ascertained that the various instrumentation required to enable a control system to function properly has to be selected taking into account what process it will be used to measure as well as what accuracy requirements were needed.

PID tuning is an integral part of a control system where proportional control is generally used as the basis of controlling process with integral and derivative incorporated to reduce steady state error, reduce the gain increase caused by the P part as well as to anticipate the error.

The Zeiger and Nicholls methods were explored and found that the ultimate cycle method used the quarter amplitude decay response to reduce oscillation amplitude by 25%. This was achieved through gain adjustment, where if the response is over-damped the gain is increased, under-damped response results in a decrease in gain. This method works well but is a very time-consuming process.

The process reaction method utilises a process reaction curve from which data is extracted in the form of the effective delay and tangent line slope which, in conjunction with the percentage change in actuator output, enables the controller P, I & D values to be calculated. This method is less time consuming, but would need further tuning once incorporated in a control system – this provides the initial settings.

Flow, level and temperature data was extracted from the process station and used to calculate the initial tune parameters to enable simulation of the systems as well as auto-tuning. The auto-tune function was found to be a great addition in achieving better transient response from the control systems. Once the control tune data was transferred the process station, the response was unsatisfactory and manual adjustment needed to be made to reduce error to acceptable levels.

300 words maximum for a summary

2. Research & System Investigation

2.1 Research

This is not the correct way to cite. You should say - Bateson states that "Robert N. Bateson describes a control system in the following manner; "A control system is a group of components that maintains a desired result by manipulating the value of another variable in the system" (Bateson, 1993)."

Robert N. Bateson describes a control system in the following manner; "A control system is a group of components that maintains a desired result by manipulating the value of another variable in the system" (Bateson, 1993). Improper Citation

Control systems are usually represented as block diagrams that consists of functions & transfer functions, etc. representing various components of the system connected by signal lines (Bateson, 1993). Correctly cited

Control systems are classified into two groups; Open and closed loop systems. Open loop systems do not control the overall system by comparing the output to the input, whereas closed loop systems do exactly that. An example of an open loop control system is a toaster, where the temperature is constant and the user will set the time to achieve the desired burn. There is no feedback in this control system. Closed loop control utilises a sensing element on the system output, which is fed back into the system input. This influence is referred to as feedback, which is the building block of closed loop control systems. The aim of a control system is to ensure that the overall response of a larger system which it is incorporated in, matches the setpoint or desired outcome as closely as possible by reducing error (Bateson, 1993). Correctly cited

The functions performed by a feedback control system are: Measurement, Decision, manipulation (Bolton, 2015). Correctly cited

Figure 1 shows a block diagram of a typical control system which utilises feedback, which is compared to the input and then used to make adjustments on the actuator to control the system.

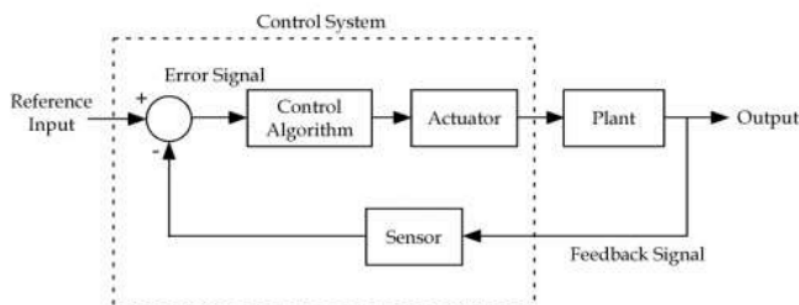


Figure 1 - Basic closed loop control system (Ledin, 2004)

The system in figure 1 is constructed from the following components; comparison element, which compares the output signal to the input signal (error signal), the control algorithm consists of a transfer function which is a mathematical representation of the system which models the system input and output relationships in a linear, time-invariant manner (Bolton, 2015). Correctly cited

The actuator is the correction element, a valve or heating or cooling element for instance, which acts on the plant to achieve the desired setpoint. The sensor is the measurement element, which could be any of a plethora of sensors, which will be further discussed in section 2.1.1, 2.1.2 and 2.1.3.

The control system response is made up of two parts; transient response and steady state response, where transient is measured from a change in input to the control system until it reaches steady state, which is the desired output after transient responses have finished. This enables modelling of any input with associated output throughout the time period of the function (Bateson, 1993).

Differential equations are the building blocks of transfer functions and can be classed as first, second, third etc. order. For a first order system the differential equation will be in the form of $\frac{dx}{dt}$, second order $\frac{d^2x}{dt^2}$ etc. which describes the rate that x changes in relation to time (Bolton, 2015).

2.1.1 Flow Control

Flow measurement in an industrial process is important, it is not only used for data recording for financial reasons but more importantly for controlling process input and outputs for functional safety amongst other functions.

A flow control system can utilise a variety of instrumentation as the sensing or output measurement element, four of these are evaluated in table 1.

From table 1 it can be seen that there are various flow measurement sensors, the selection of a particular method or sensor will depend on process conditions and accuracy requirements.

Flow Measurement Methods				
Method	Operation	Placement	Equation	Principle
Differential pressure	Measures the difference in pressure across a restriction in a process line.	Orifice plate	$Q = K \sqrt{\frac{h}{\rho}}$	Flow rate is proportional to the square root of measured pressure drop
Turbine	One turbine blade houses a small permanent magnet, which creates a pulse in conjunction with a sensing coil	In-Situ	$V = KN$ and $q = Kf$	Pulses relate to volume of process passing through meter. V = Total process volume, K = volume of process/pulse, N = no. of pulses
Magnetic	Measures induced voltage caused by conductive liquids moving through a magnetic field	Non-intrusive	$E = kxBxDxV$	Operates in accordance to Farady's law - electrically conductive liquids cut magnetic fields.
Coriolis	Mass flow rate measured through the principle of motion mechanics	In-situ	Mass flow = $F_c/(2\omega x)$	Process is split into two tubes - Tubes are oppositely oscillated at natural resonant frequency and time delay in created sinewave is proportional to mass flow rate

Table 1 - Flow Measurement Methods (Emerson, 2021) (Liptak, 2003)

Appendix figure 1 shows a simple process flow control diagram P&ID, consisting of a pump, flow transmitter, flow controller, I/P (current to pressure) converter and flow control valve.

The flow transmitter measures the flow through the process line, produces a 4-20mA signal which feedback in relation to the set point. The flow controller will then produce a suitable signal which will be converted from 4-20mA to a 3 -15psi pneumatic signal in the I/P to control the valve position.

This system is at least a second order system, due to the sensing, feedback and control elements.

2.1.2 Level Control

Level control in industrial process is usually in the form of 1st order, as there are two scenarios to consider. Firstly, if there is flow into a vessel and flow out of a vessel, the system will be classed as a 1st order system. In the case of a tank that is just filled and kept at a specific level, the system would be seen as using only integrator control.

Level Measurement Methods				
Method	Operation	Placement	Equation	Principle
Differential Pressure	Measures the difference in pressure between the bottom and a specified higher point	Side of vessel / tank - direct contact	Hydrostatic pressure = process density x gravity x height	Pressure differential times specific gravity
Displacer	Displacer body/float as force exerted upon it, this force is measured	Side of vessel / tank - direct contact	Archimedes' principle of buoyancy	Length of displacer chamber times the specific gravity of process
Radar	Radar antenna generates electromagnetic pulse which travels at the speed of light and is reflected by process	On top of tank / vessel - no contact or probe into process referred to as guided wave	Distance = [speed of light x time delay]/2	High frequency radio waves in the GHz range
Floats (magnet / reed switch)	Ferrous float housed in non-ferrous chamber - as float moves reed switches are triggered	Float is in contact with process - Reed switches are not	N/A	Transmitter resolution determined by reed switches per unit of measure

Table 2 - Level Measurement Methods (Emerson, 2021) (Liptak, 2003)

Table 3 - Level Measurement Methods

Four different level measurement elements are briefly discussed in table 1. The selection of an appropriate sensor will depend on the process that it will be used on. Differential pressure transmitters can be used on vessels with a large span, where a "wet leg" low pressure, filled with barrier fluid will be used to calculate the range as well as upper and lower values of the transmitter. The specific gravity of the barrier fluid and process fluid is needed to carry out the calculations.

2.1.3 Temperature Control

Temperature control is thermal lagging dependant – if there is heat in and heat out the control system will be 1st order, as the temperature rises linearly and has to stop at 100deg for water.

If no there's no heat loss, it will be integrator only.

Table 2 shows briefly explains industrial temperature measurement methods which are the sensing elements in the control loop. The temperature controller, which can incorporate P, PI or PID control will adjust flows or burner / element intensity to achieve the setpoint for example.

Industrial Temperature Measurement Methods				
Method	Operation	Placement	Equation	Principle
Thermocouple	Temperature is measured at the HJ, a mV signal is measure at the CJ, which is then fed to a transmitter via compensating cable which compensates for the ambient temperature.	Generally housed in a thermowell to provide protection from process.	μV or mV / Degree dependant on material used in hot junction.	Dissimilar metals joined to form hot junction (measurement end) and a cold junction, where the open circuit voltage is measured - Called Seebeck voltage. Classified as K-type, J-type, S-type amongst others.
Resistive Temperature Detectors (RTD)	Resistive material which exhibits a change in resistance with change in temperature	Generally housed in a thermowell to provide protection from process.	Example PT100 = platinum material gives 100 Ω at 0deg. C	Relationship of resistance change vs. temperature referred to as alpha curve. Variants - 2-wire / 3-wire and 4-wire. Larger amount of "wires" = more accuracy
Infrared Pyrometer	Non-contact radiant energy detector	Non-contact - placed outside a furnace through a treated glass optical path	Radiant in tensity and flux	The amount of radiant energy is proportional to temperature of process in relation to target temperature - in line with Planc's Law of thermal radiation

Table 4 - Temperature Measurement Methods (Liptak, 2003) (Bolton, 2015)

2.1.4 Process Control Philosophies

Industrial continuous process control aims to match the output of a system to a defined set point; this is achieved by continually comparing the output to the input and making the necessary changes to achieve the set point.

The most common industrial control modes are; proportional (P), integral (I) and derivative (D), these modes can be used individually or together in the form of P, PI, PD, or PID, depending on conditions (Bateson, 1993).

	Principle	Example	Considerations
Proportional (P)	Produces a change in the controller <i>proportional</i> to the error signal	Simple float level control acting on a valve - when the tank is empty the valve will be 100% open, as the tank fills the valve will close proportionally as the error reduces	Gain has to be set to a acceptable value without resulting in oscillation.
Integral	Output is changed by an amount proportional to the <i>integral</i> of the error signal	Not used stand-alone as integral only will cause transient overshoot and saturation used in conjunction with P or P and D	As long as some error exists the integral control will change the output at a rate proportional to the error
Proportional /integral - PI	P provides a change in controller output proportional to the error and integral will add additional output change proportional to the <i>integral</i> of the error	Used in processes where rapid changes in loads are present and tight tolerances are required, for instance heat exchanger temperature control.	During rapid proses changes P cannot reduce the offset enough - I provides a reset action that reduces the proportional offset.
Derivative	Output is changed by an amount proportional to the rate of change of the error signal	Never used alone - used to increase system stability, improve transient response and reduces overshoot. Acts in an error anticipatory manner	Derivative control only acts on the controller output whilst there is an error present

Table 5 - P I D Explained (Bateson, 1993) (Bolton, 2015)

From table 2 it is clear to see that proportional control reacts to an error in output, which is a deviation from the set point in a direct or proportional manner, which can cause a large proportional offset. Integral control is then added, if needed, to reduce the proportional offset by changing the output by an amount proportional to the integral value of the error. Derivative

control can then be added if the process setpoint and output still do not match, where it will anticipate the rate of change of the error in an anticipatory manner (Bolton, 2015).

	Steady State Error	Overshoot	Rise Time	Settling Time
P	Decreases	Increases	Decreases	Minor Change
I	Eliminates	Increases	Decreases	Increases
D	Minor Change	Decreases	Minor Change	Decreases

Table 6 - Transient Response Effect of P I D (ToolBox, 2021)

Table 2 shows the various effects that P, I & D control philosophies have on process response, where steady state error is the deviation once the process has settled compared to the setpoint, overshoot is the initial rise response curve, rise time is how long the long the response takes to reach the final value which depends on damped value (usually 5% - 95% for critically damped systems) and finally settling time is the time taken to reach an acceptable error (Mathworks, 2021).

Appendix figure 3 shows a graphical representation of a second order response settling time and rise time.

Table 3 shows a brief summary of the advantages and disadvantages of P, PI and PD control.

	Advantages	Disadvantages
Proportional	Easily implemented	Longer settling time and inherent steady state error
Proportional / Integral	No steady state error	Narrow stability range
Proportional / Derivative	More stable and faster response	Possibility of amplifying noise

Table 7 - Advantages and Disadvantages of P, PI, PD Control Summary (Bolton, 2015) (Bateson, 1993)

Digital control is being used in process control more frequently where a microprocessor will have a program stored on it and could run several different variables. The basic layout of a closed loop digital controller consists of an input signal that is converted to a digital code by an ADC, this is fed into the microprocessor where the correction is applied and then fed to a DAC to be converted to an analogue signal which is fed to the process control mechanism. The ADC, microprocessor and DAC are controlled by a clock which sets the sampling interval. The measurement element feeds output error to the input before the ADC (Bolton, 2015).

Correctly cited

2.1.4.1 Tuning Methods

To achieve accurate or desired process control, the PID controller needs to be tuned. This can be done using three different methods. These methods are briefly discussed in table***.

The basis of controller manual tuning is to model the process that the controller will be used on, once this model has been created certain parameters can be obtained to enable the simulation and tuning process. Once the process is simulated, the transient response can be analysed and the values of P, I and D adjusted to obtain the desired response. The tuning starts with setting P part to achieve some oscillations and a fast rise time, followed by adjusting the integrator value to reduce the oscillations, which could introduce some overshoot. The derivative values are then adjusted to reduce overshoot and ensure the steady state error is within limits (Bateson, 1993).

The two Zeiger & Nicolls methods are the ultimate cycle and process reaction method. The ultimate cycle requires the controller to be installed with the system ready to operate, the ultimate gain (minimum gain for controller oscillation) and ultimate period (oscillation period) needs to be ascertained. These values are then used in conjunction with the equations in table 5 to obtain a ¼ oscillation amplitude decay (Bateson, 1993) (Bolton, 2015).

	Ultimate Cycle Method	Process Reaction	Process Reaction variable values
P	$P = 0.5G_u$	$P = \frac{\Delta P}{NL}$	$L = \text{Effective Delay}$ $N = \frac{\Delta C_m}{\Delta t}$ $\Delta P =$ <i>Change in manipulating element</i>
PI	$P = 0.45G_u$ $I = \frac{1.2}{P_u} (\text{min}^{-1})$	$P = 0.9 \left(\frac{\Delta P}{NL} \right)$ $I = \frac{0.3}{L} \text{min}^{-1}$	
PID	$I = \frac{2.0}{P_u} (\text{min}^{-1})$ $D = \frac{P_u}{8} (\text{min}^{-1})$ $P = 0.6G_u$	$P = 1.2 \left(\frac{\Delta P}{NL} \right)$ $I = \frac{0.5}{L} \text{min}^{-1}$ $D = 0.5L \text{min}$	

Table 8 - Zeiger & Nichols Methods Equations (Bateson, 1993)

The quarter amplitude reduction is shown in figure 2.

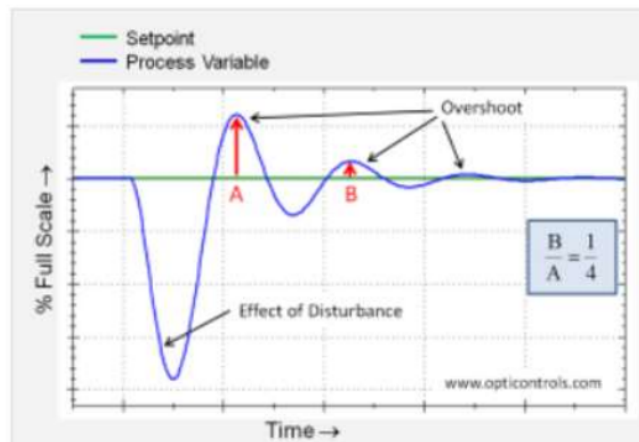


Figure 2 - Ultimate Cycle 1/4 Oscillation Amplitude Reduction (Smuts, 2021)

The process reaction method assumes a first order lag and dead-time model approximation of process can be obtained. With the process in open loop, the measured variant has to be steady after which a disturbance is introduced and the controlled variable response recorded and referred to as the process reaction curve, which is S-shaped. As shown in appendix figure 5. The equations in table 5 are used to calculate the P, I, & D values (Bolton, 2015).

Software programs (like MATLAB's Simulink) can perform auto tuning, where the controller values are automatically determined.

2.1.5 CIM System Investigation

The process station control loops consist of a flow, level and temperature control loop, integrated in a manner which allows them to function individually or in cascade. The full control system P&ID, can be seen in appendix figure 6, with the individual control loops for flow, level and temperature are appendix figures 7, 8 and 9 respectively.

The closed loop flow control system, similar to the loop previously mentioned in this assignment, is constructed with FT535, flow transmitter, which is the sensing element, FC535, which is the controlling element and LY541 which controls the DC pump. LT541 measures tank B1 level, this signal is fed to LC541 which also has an input to LY541 for DC pump control as well as V500 tank B1 drain valve, this loop is an open loop first order control system.

The temperature loop P&ID shows that a heating element in tank B1 is controlled by TC511 which has the tank temperature value measured by TT511. This loop has a safety interlock built in, where in the event that LS542 shows a low level the heating element will de-energise to stop the element burning out. Incorporated in this loop is the option to divert the cleaning process through a cooling matrix cooled by a fan, all of which are controlled by TC511 and LY541. Referring to the research previously conducted it is clear to state that this temperature loop is a first order closed loop system.

3. Flow Control System

Original response simulation with data extracted from process station

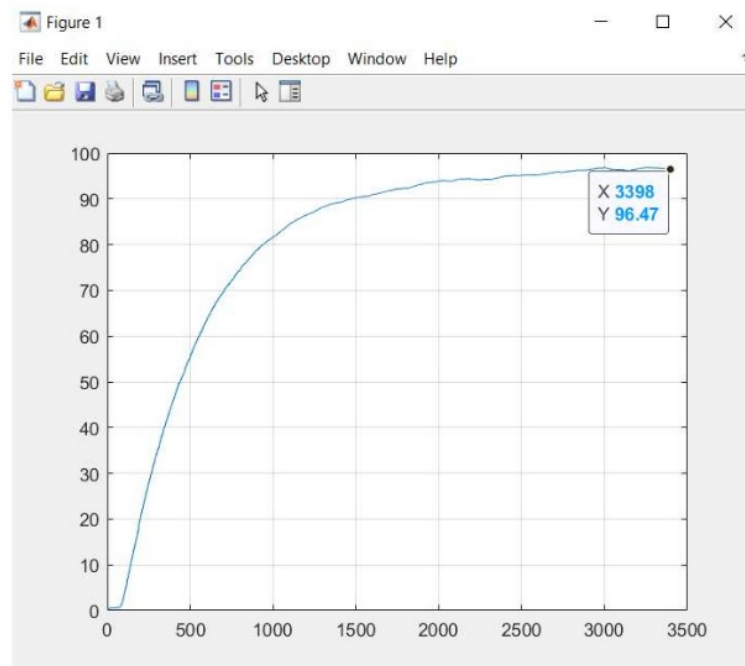


Figure 3 - Initial Response From Process Data

Initial response and auto tuned response using Simulink

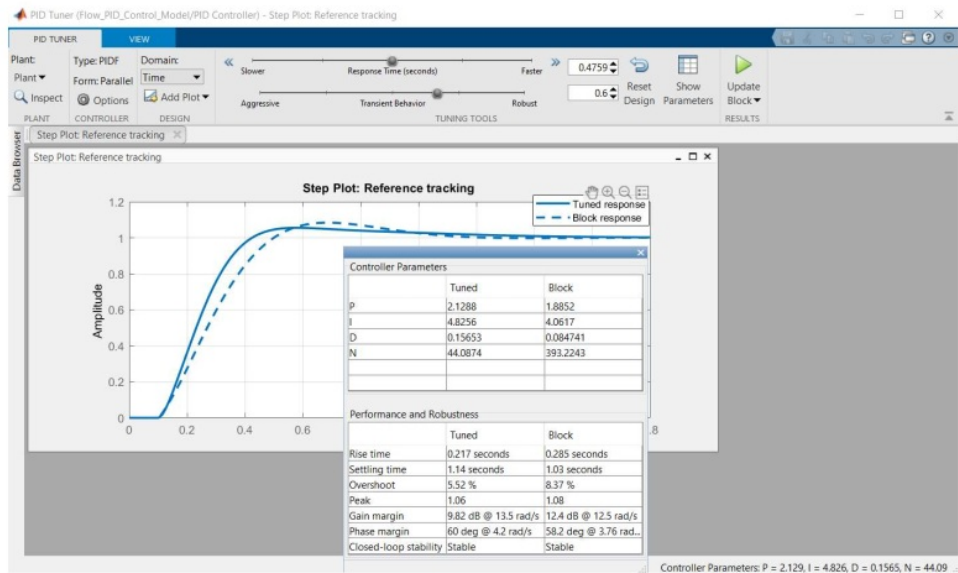


Figure 4 - Flow Control Tuning

Using Caldwell's method, the transfer function values calculated are (For calculations see appendix 9.2):

$$G(s) = \frac{24.12}{s^2 + 12.8s + 24.12}$$

Simulink model of control system with calculated values;

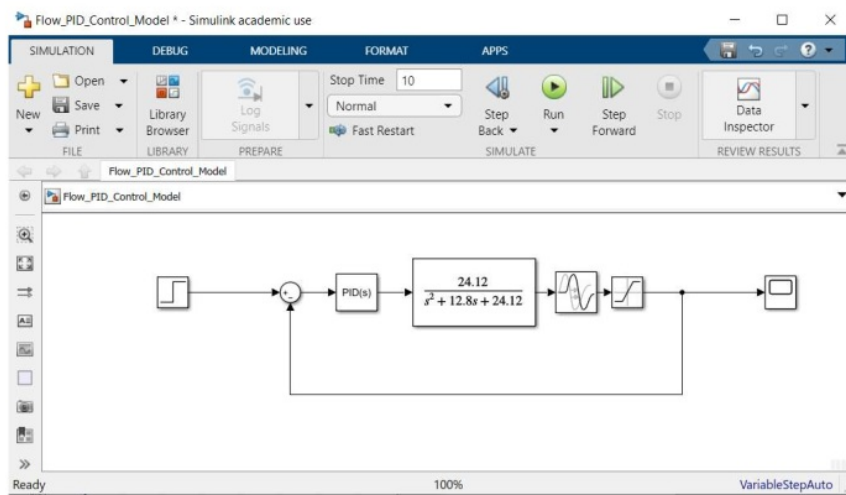


Figure 5 - Flow Control System with Calculated Values

Final Tuned response

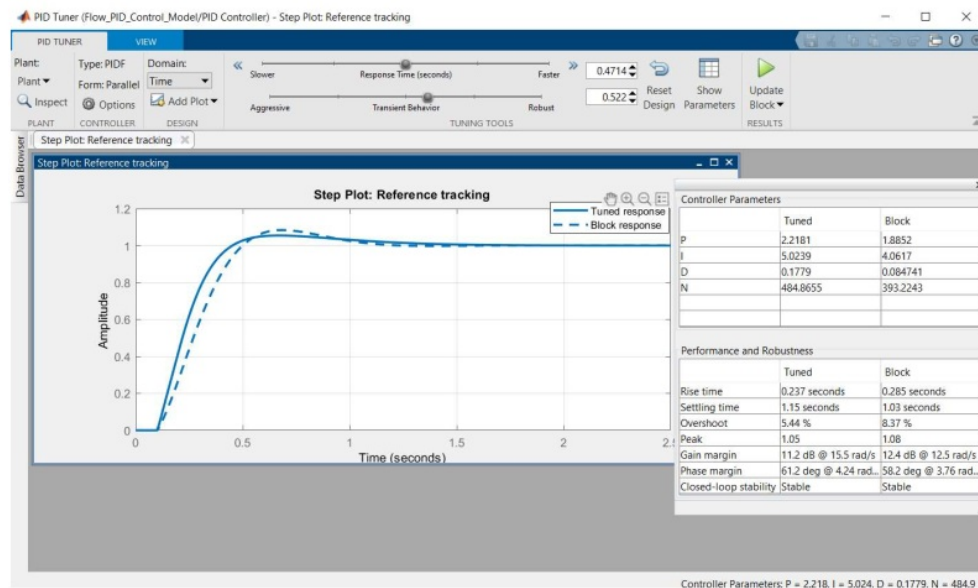


Figure 6 – Final Flow Auto-Tuned Response

Further testing conducted on the process station resulted in the P, I & D tuned values being altered to a value that resulted in a more suitable practical response as shown in figure 7.

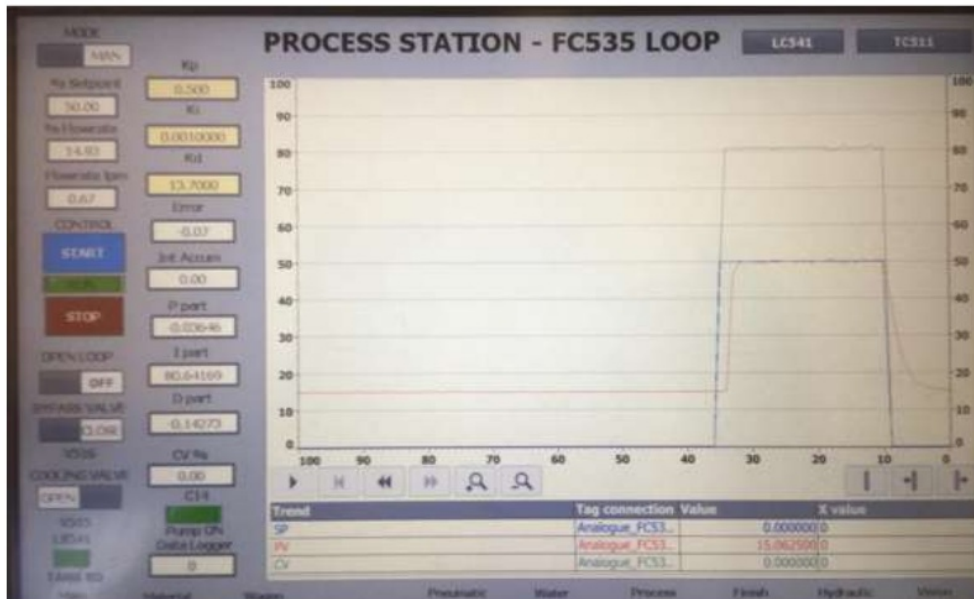


Figure 7 - Process Station Flow Control Tuning

Don't understand what you mean by before and after Caldwell tuning?

	Before Caldwell tune		After Caldwell Tune		CIM As left	
	Tuned	Original	Tuned	Original		
P	2.129	1.885	2.218	1.885	0.5	
I	4.826	4.062	5.024	4.062	0.001	
D	0.1565	0.085	0.1779	0.085	13.7	
Rise Time	0.217s	0.285s	0.237s	0.285s		
Settling Time	1.14s	1.03s	1.15s	1.03s		
Overshoot	5.52%	8.37%	5.44%	8.37%		

Table 9 - Flow Tune Values

From table 9 an evaluation can be made that, the tuned values generally reduce rise time, at a slight increase in settling time. The overshoot on the tuned values is much less. This proves that the Caldwell method has reduced overshoot with rise time and settling time not greatly affected.

4. Level Control System

Level control data obtained from the process station enabled the simulating of the system on Simulink. The gradient was used to calculate the transfer function, calculations can be seen in appendix 9.3.

Transfer function $G = \frac{0.105}{s}$ added to the control system, as well as a PD controller as shown in figure 8.

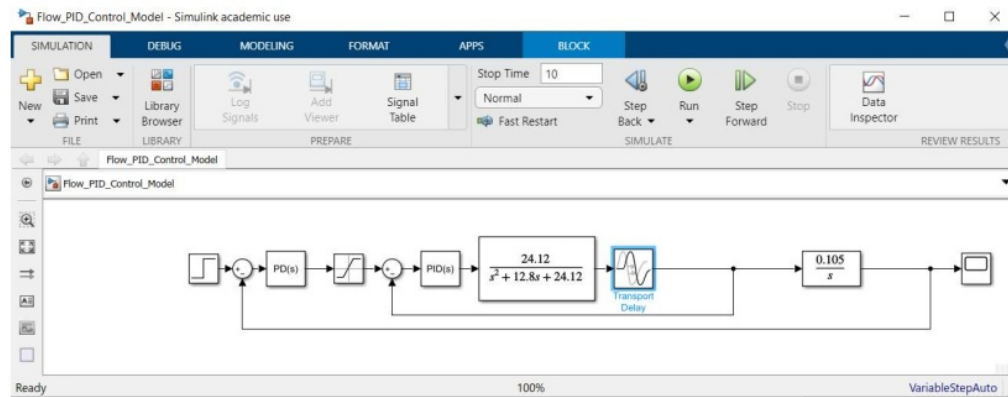


Figure 8 - Level Control System

The PD controller tuned after adding the additional control methods shown in figure 9, showing slight overshoot and some oscillation. Tuned rise time and settling time is improved, at the cost of 1.79% overshoot.

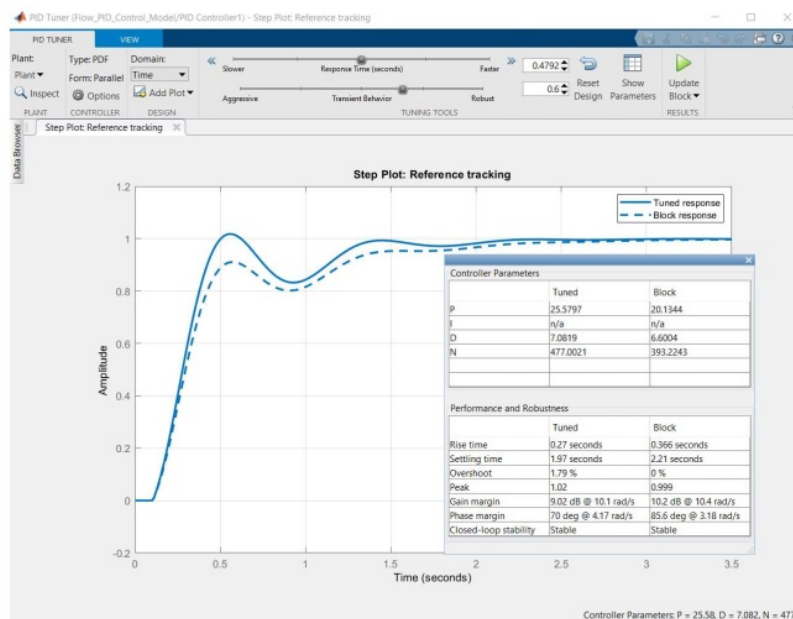


Figure 9 - PID Controller Tune After Level Ammendments

Figure 10 shows the final response curve after tuning the system, the overshoot has been reduced to 0% with improved rise and settling times.

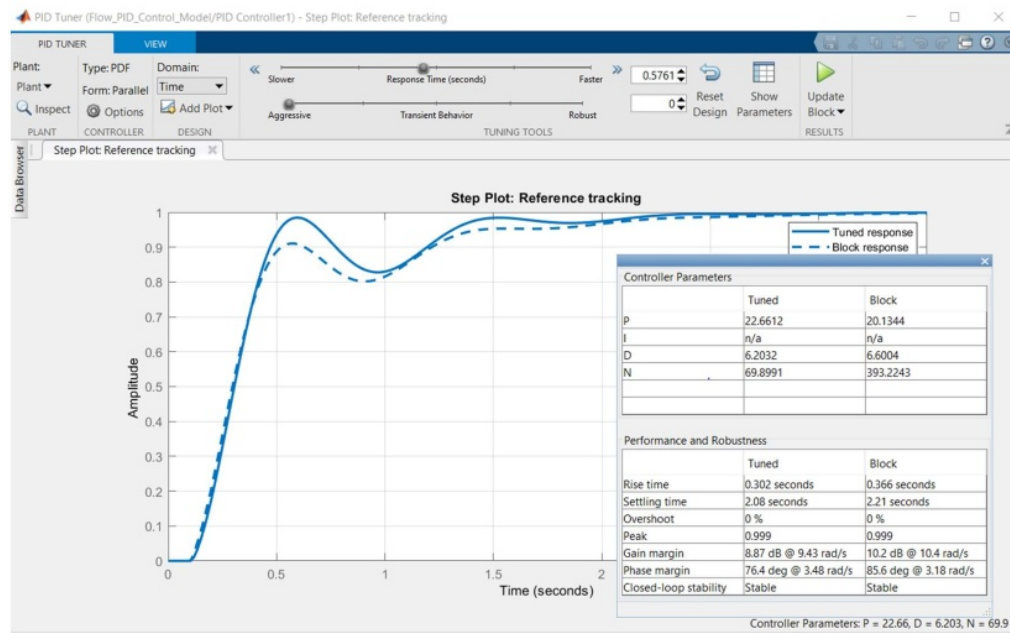


Figure 10 - Level Final Tuned Response

Simulink has a linearisation function, which slightly improved rise and settling time, with no overshoot, whilst reducing the gain as well, shown in figure 11.

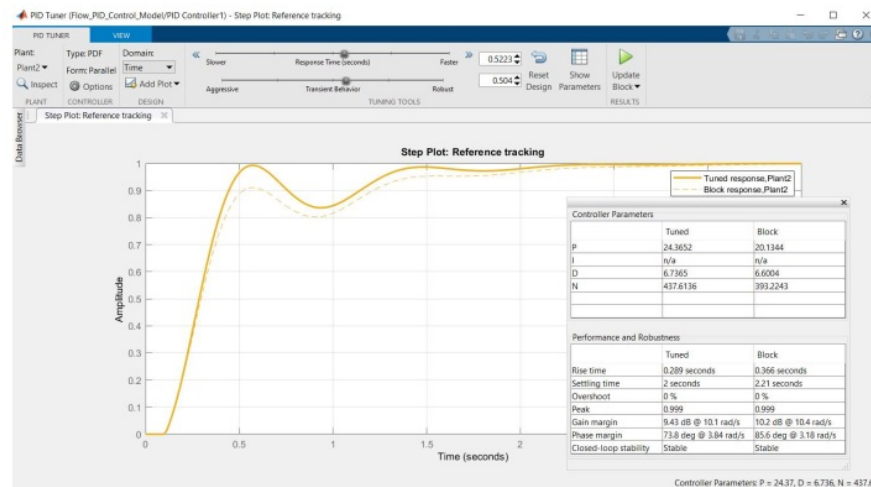


Figure 11 - Simulink Linearisation Function – Level

The tuned configurations resulted in an unacceptable response on the process station, which resulted in the values being manually tuned to obtain an acceptable response, shown in figure 12.

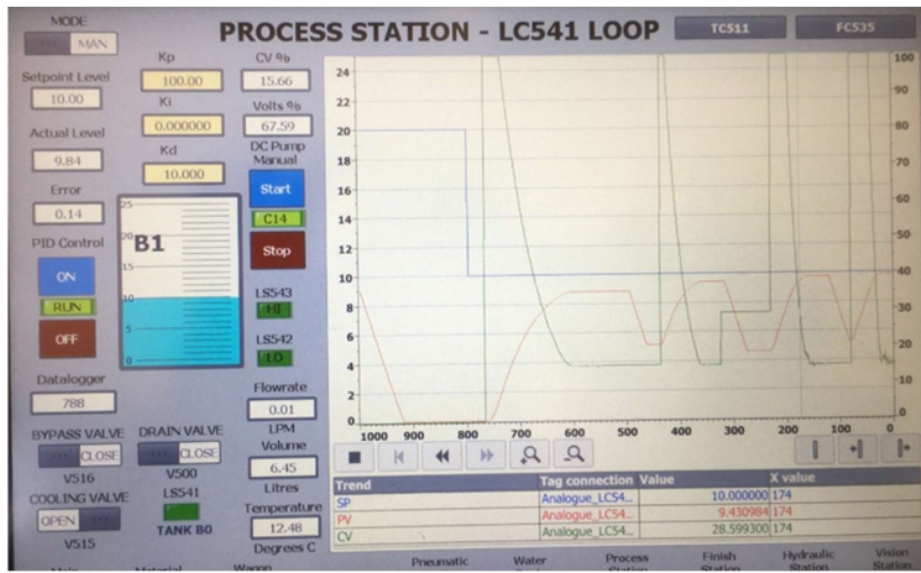


Figure 12 - Process Station Manual Tuning Response - Level

This is not auto tuning, it is model based where the auto tuning was performed in Simulink and values used as starting values on the system
The final results are shown in table 10.

	Initial Auto Tune		Final Autotune		CIM As left	
	Tuned	Original	Tuned	Original		
P	25.58	20.134	22.661	20.134	100	
D	7.082	6.06	6.203	6.06	10	
Rise Time	0.27s	0.366s	0.302s	0.366s		
Settling Time	1.97s	2.21s	2.08s	2.21s		
Overshoot	1.79%	0%	0%	0%		

Table 10 - Level Control Tuning Results

The autotune rise-time, settling-time and overshoot shows a good improvement during the initial auto tune but the response did overshoot by 1.79%. The final autotune compromised on rise and settling time to give 0% overshoot, albeit still within acceptable parameters.

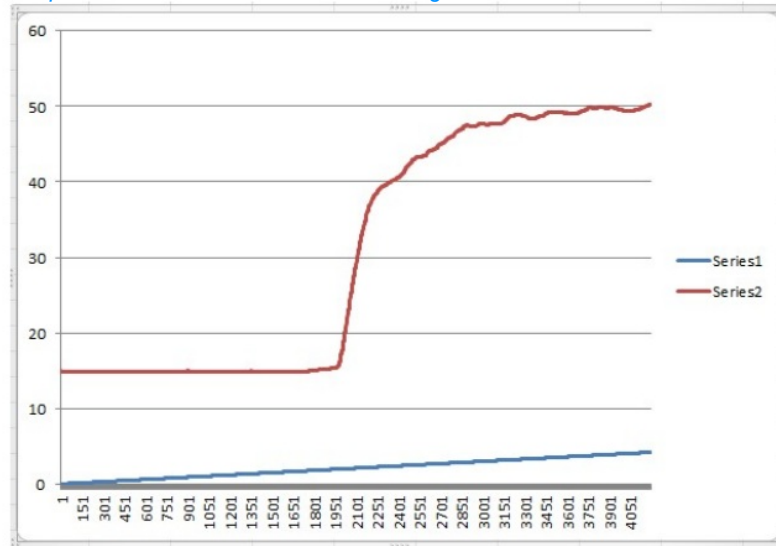
Practical process station tuning resulted in large increases in both P & D values compared to simulated results, to achieve acceptable error values

It is clear to see from the results that the simulated values are based on a perfect model, whereas in reality process units will have unaccounted inaccuracies or disturbances that will affect control performance. This highlights the need for control engineers to have the skill to carry out manual tuning, that suits real-world process conditions.

5. Temperature Control System

Response plotted from the data extracted from the CIM system show shown in graph 1 where there is a large lag in response before a steep increase in temperature, as the heating element catches up, followed by reasonable control to setpoint with no overshoot.

This is incorrect, the temperature should have risen as a straight line



Graph 1 - CIM Extracted Temperature Response

This data enabled a gradient to be measured and subsequently a transfer function to be calculated, as shown in appendix 9.3.

Transfer function derived $G = \frac{0.075}{s}$ added to the control op simulation, shown in figure 13.

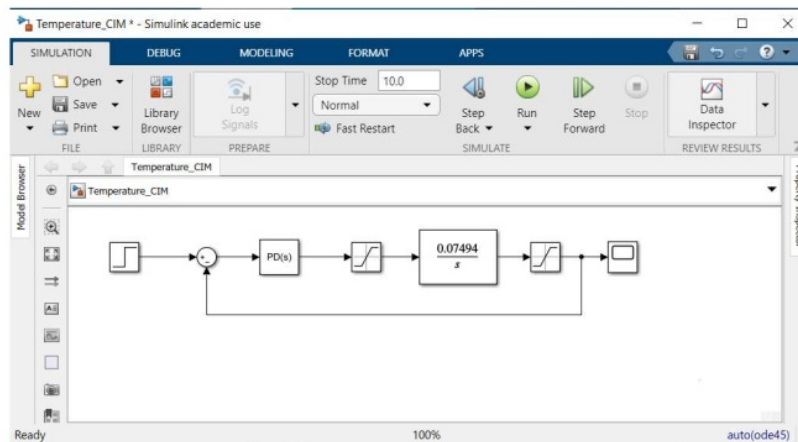


Figure 13 - Temperature Control Loop Simulation

This is what the process reaction curve should have looked like

The initial results from Simulink shows a very linear response with no overshoot.

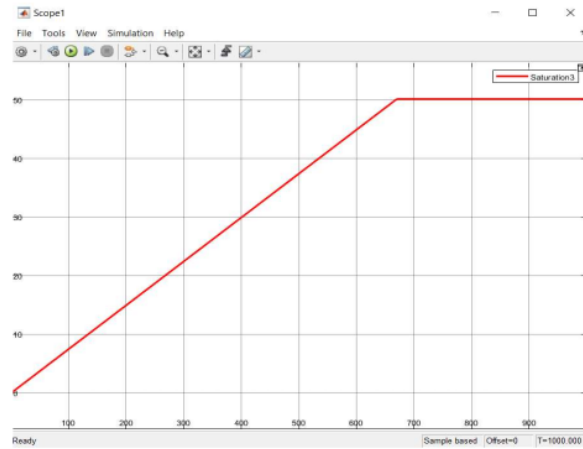


Figure 14 - Temperature Control Loop Response

Figure 15 shows the initial response and tuned response, it is clear to see that the rise and settling time is higher with the tuned results, but this will give a more efficient and controlled system.

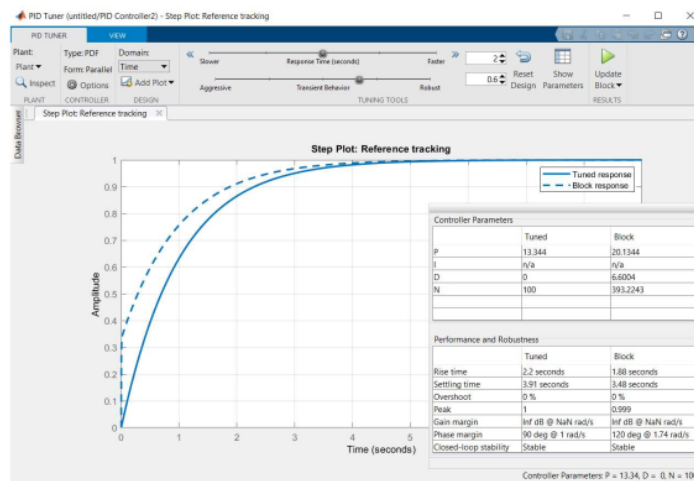


Figure 15 - First Auto Tune Attempt – Temperature

Figure 16 shows the temperature response after manual tuning was carried out to improve response. The rise and settling times are greatly improved, again with no overshoot, this is with the derivative set to 0. The proportional control will control the system well, until disturbances start action on the process.

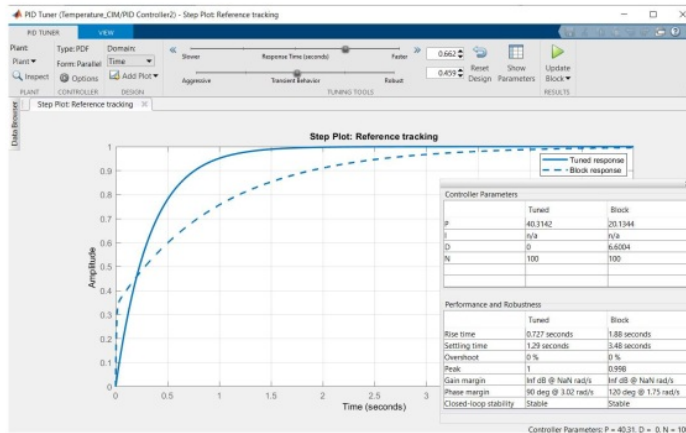


Figure 16 - Manually Tuned P Value Response – Temperature *be consistent with your font size justification and line spacing*

From figure 17, with the proportional value set to 35, a more acceptable response can be obtained. The Simulink initial tune result for P resulted in an unacceptable response, whereas the manually tuned Simulink value (figure 16), was more realistic to the process station physical value.

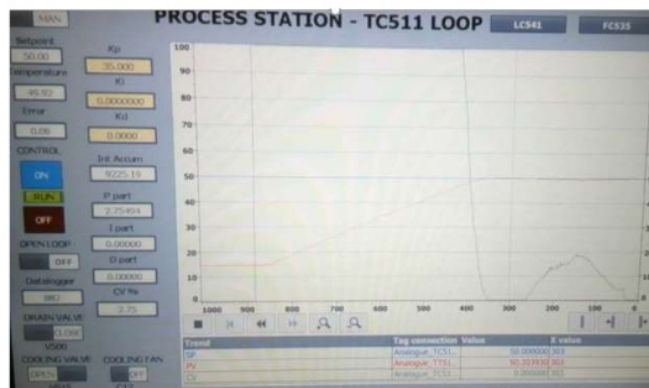


Figure 17 - CIM System Manually Tuned P Value

From the results in table 11 a conclusion can be made that derivative control is not needed in this system; proportional control can give acceptable response parameters as there are little to no disturbances acting on the system. In the event that disturbances regularly act on this process the derivatives part could be used to predict the error and respond appropriately.

	Initial Auto Tune		Manual S.link tune		CIM As left	
	Tuned	Original	Tuned	Original		
P	13.344	20.134	40.314	20.134	35	
D	0	6.6	0	6.6	0	
Rise Time	2.2s	1.88s	0.727s	1.88s		
Settling Time	3.91s	3.48s	1.29s	3.48s		
Overshoot	0.00%	0%	0%	0%		

6. Conclusions and Recommendations

Thorough research enabled a sound understanding of control theory and the associated instruments available to a control systems engineer to assist in ensuring safe, reliable, cost effective environmentally friendly control systems.

There are a large amount of industrial flow, level and temperature measurement instruments available, where the selection depends on the process it will be used in as well as control system requirements. These instruments are the backbone of any associated control system.

Proportional control can be used as a standalone method, whereas integral and derivative are better suited to be used in conjunction with proportional, as they complement the proportional gain increases and error anticipation.

The simulations carried out on Simulink enabled auto-tuning of the control systems as well enabled the user to ascertain which control philosophy is required. It was clear to see that in the case of the temperature controller, derivative control was not needed.

The Caldwell method used to calculate the flow transfer function proved to be a successful method, as the response overshoot was reduced, whilst keeping the rise and settling time virtually unchanged.

The calculated and simulated control values did not produce acceptable results when uploaded to the process station, where all values had to be manually obtained.

These errors are partly due to inaccuracies in the measurement instrumentation and non-linear pump output.

More time spent on tuning the sub-systems, in addition to accurate instrumentation will enable more accurate control.

Use full justification

7. Team Working

Covid restrictions meant that traditional team working could not be carried out in a safe manner, this led to the need for tasks to be carried out individually and then shared amongst the other team members, who would redo the tasks to gain an understanding of the associated methods.

Travel restrictions and PPE requirements were adhered to nonetheless and a thorough understanding of the tuning process was gained by all members of the team.

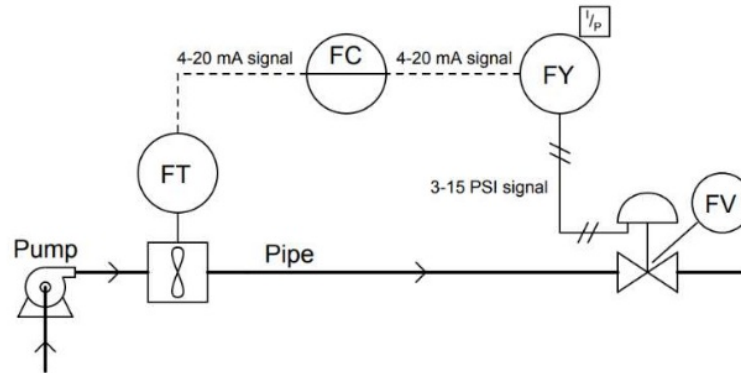
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9. Appendix

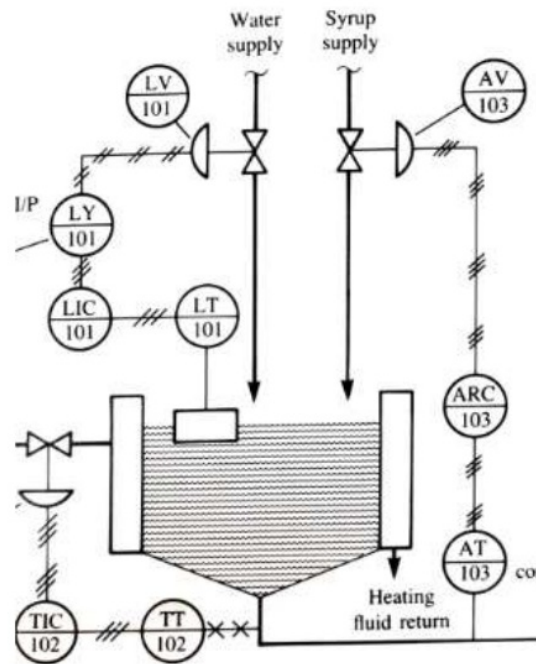
9.1 Research

9.1.1 – Flow Control P&ID

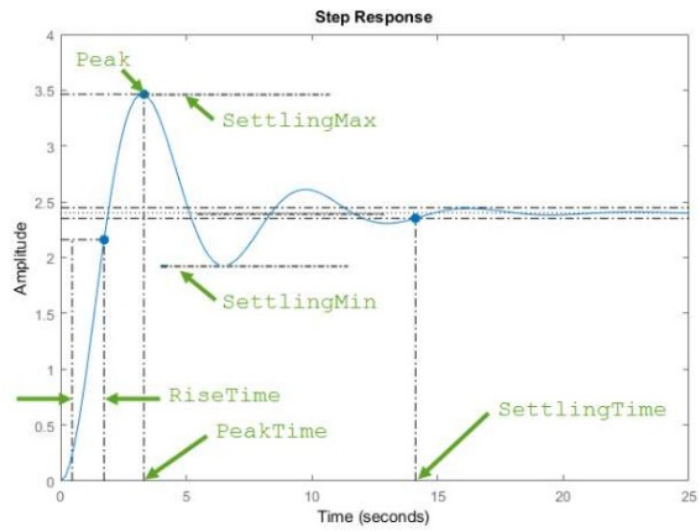


Appendix Figure 1 - Flow Control P&ID (Liptak, 2003)

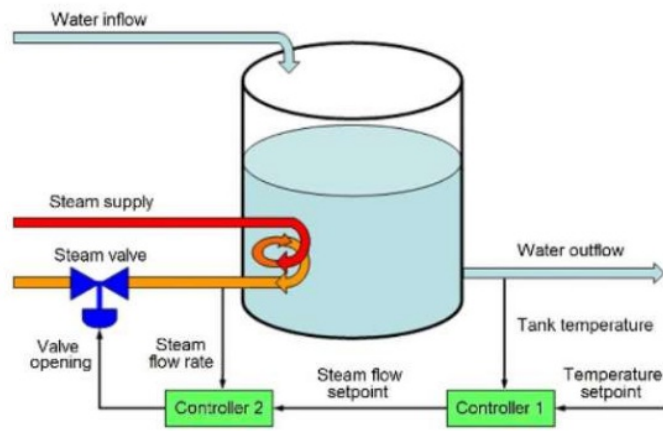
9.1.2 - Level control P&ID



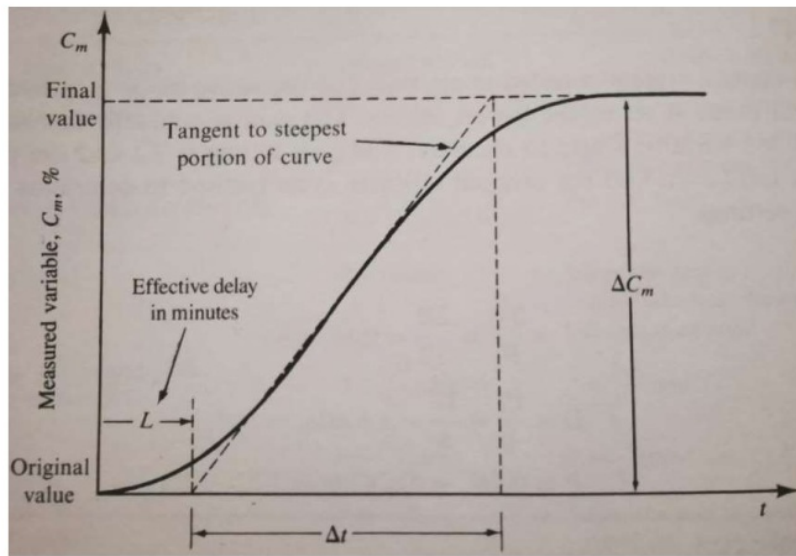
Appendix Figure 2 - Level Control P&ID (Liptak, 2003)



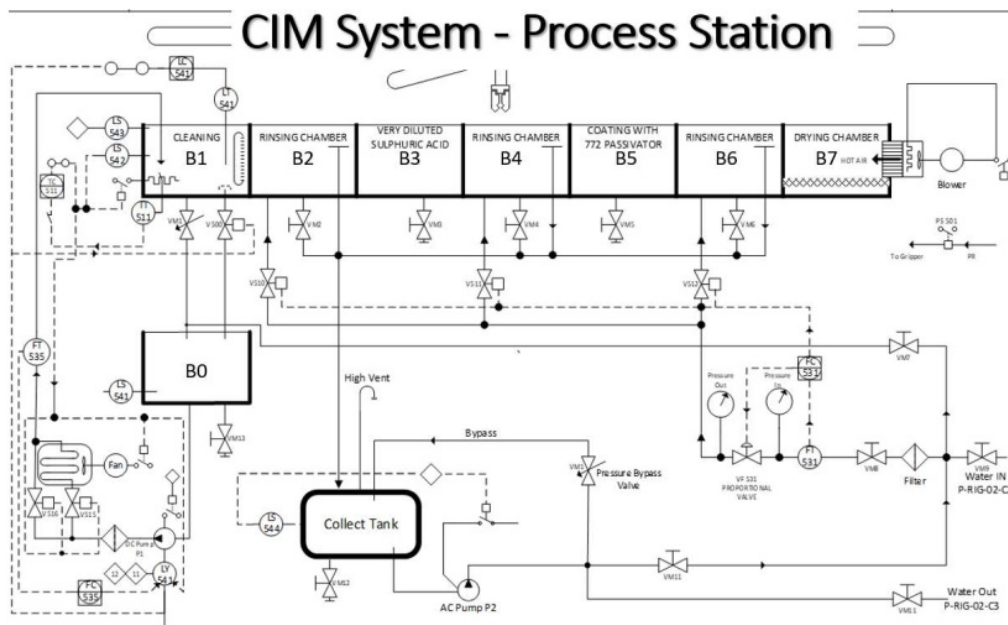
Appendix Figure 3 - Second Order Response Rise and Settling Time (Mathworks, 2021)



Appendix Figure 4 - Typical Industrial Temperature Control Loop (Vandoren, 2014)

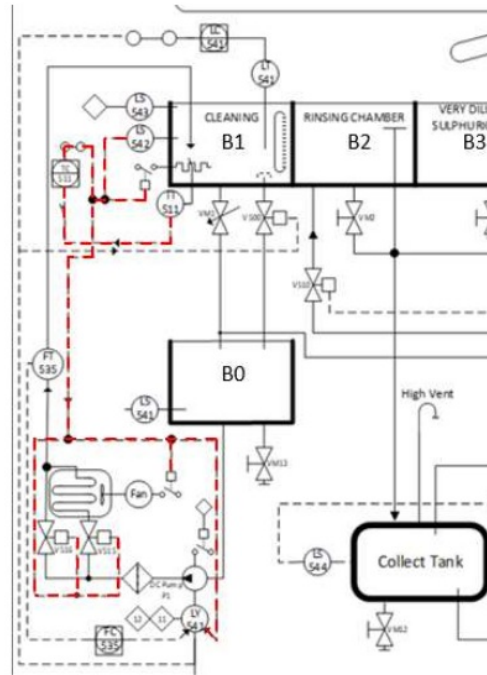


Appendix Figure 5 - Process Reaction Graph (Bateson, 1993)



Appendix Figure 6 - Process Station P&ID





Appendix Figure 9 - Process Station Temperature P&ID

9.2 Flow

Process station data to calculate transfer function values;

$$ty = \left[\frac{96.46}{100} \right] \times 73 = 70.416 \text{ or } 0.70 \text{ seconds}$$

$$r1 + r2 = \frac{ty}{1.32} = \frac{0.7}{1.32} = 0.5303$$

$$tx = \frac{r1 + r2}{2} = \frac{0.5303}{2} = 0.2652$$

$$x = \frac{30.377}{96.46} = 0.315$$

From Caldwell reference graph at 0.315 = 0.82

$$\tau2 = 0.82 \times (\tau1 + \tau2) = 0.82 \times 0.5303 = 0.435$$

$$\tau1 = (\tau1 + \tau2) - \tau2 = 0.5303 - 0.435 = 0.0953$$

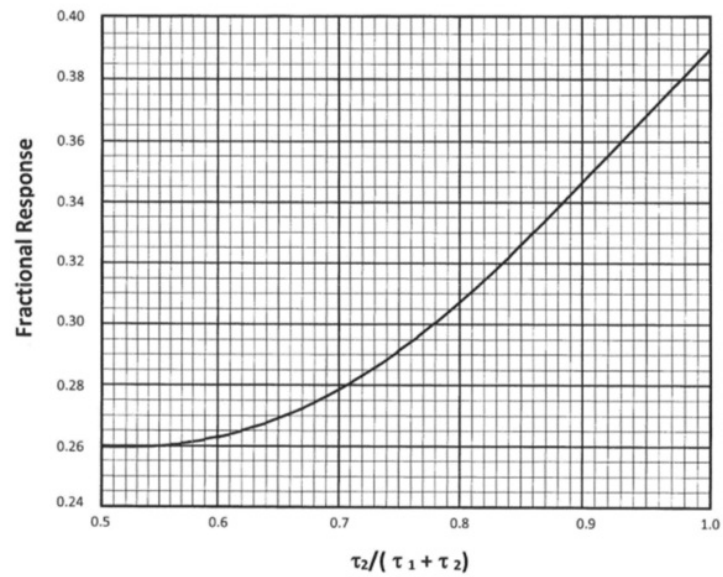
$$G(s) = \frac{\frac{1}{\tau_1 \tau_2}}{s^2 + \left(\frac{\tau_1 + \tau_2}{\tau_1 \tau_2}\right)s + \left(\frac{1}{\tau_1 \tau_2}\right)}$$

$$\frac{1}{\tau_1 \tau_2} = \frac{1}{0.0953 \times 0.435} = 24.12$$

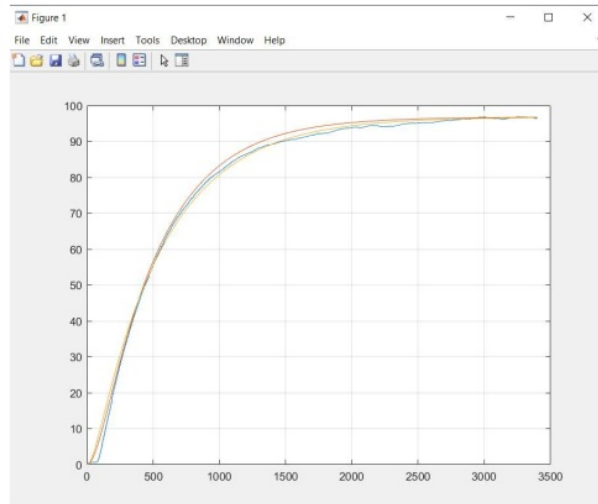
$$\frac{\tau_1 + \tau_2}{\tau_1 \tau_2} = 0.5303 \times 24.12 = 12.8$$

Therefore:

$$G(s) = \frac{24.12}{s^2 + 12.8s + 24.12}$$

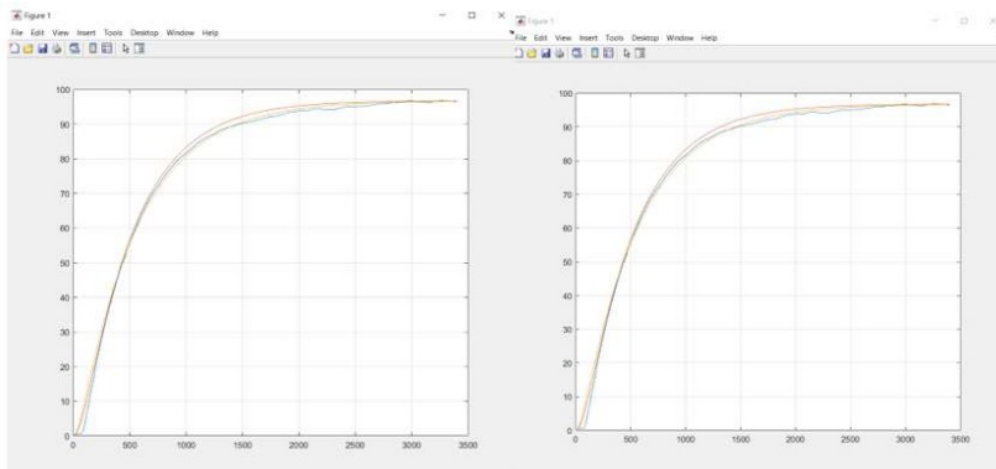


Appendix Figure 10 - Caldwell's Method Graph



Appendix Figure 11 - Flow Response Using Values Calculated Using Caldwell's

Comparison of calculated (left) and adjusted (right) values



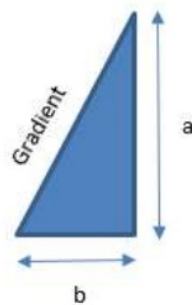
9.3 Level

Process station level gradient

$$a = 62, 17.8$$

$$b = 193, 4.11$$

$$17.8 - 4.11 = 13.69$$



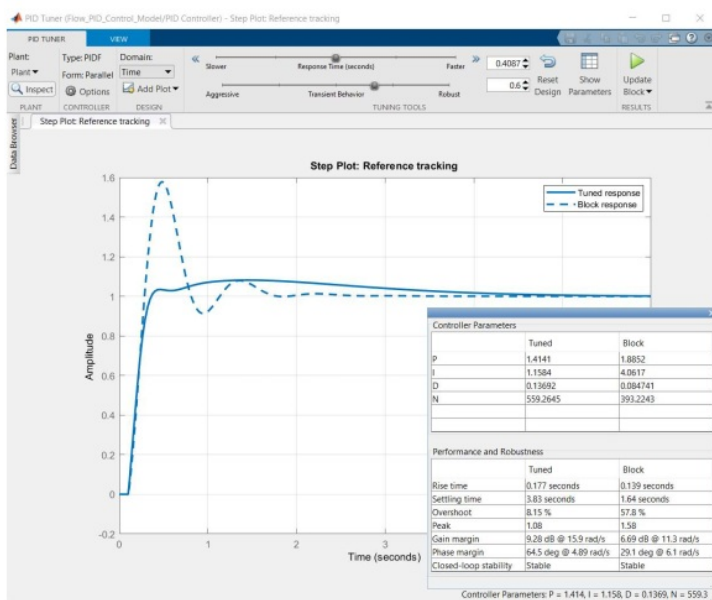
$$193 - 62 = 131$$

To calculate gradient;

$$Grad. = \frac{13.69}{131} = 0.1045 = 0.105$$

Transfer function derived to be $G = \frac{0.105}{s}$

Auto tune on the PID controller after adding second transfer function & PD controller.



9.3 Temperature

$$a = 295, 49.2$$

$$b = 732, 16.45$$



$$49.2 - 16.45 = 32.75$$

$$732 - 295 = 437$$

To calculate gradient;

$$Grad. = \frac{32.75}{437} = 0.07494 = 0.075$$

Transfer function derived to be $G = \frac{0.075}{s}$

1809797

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GENERAL COMMENTS

Instructor

60/100

PAGE 1

Text Comment. I understand that something has gone wrong with the pdf conversion for page numbers

PAGE 2

PAGE 3

PAGE 4

Text Comment. 300 words maximum for a summary

PAGE 5

Text Comment. This is not the correct way to cite. You should say - Bateson states that " " (1993, pg)

QM

Improper Citation

Improper citation:

Improperly cited material. Please use the link below to find links to information regarding specific citation styles: http://www.plagiarism.org/plag_article_citation_styles.html

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Text Comment. Don't understand what you mean by before and after Caldwell tuning?

Text Comment. This is not auto tuning, it is model based where the auto tuning was performed in Simulink and values used as starting values on the system

Text Comment. This is incorrect, the temperature should have risen as a straight line

Text Comment. This is what the process reaction curve should have looked like

Text Comment. be consistent with your font size justification and line spacing

Text Comment. Use full justification

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BRITS**

60

1. ENGAGEMENT WITH LITERATURE



Engagement with a wide range of literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing, with no/very few inaccuracies or inconsistencies (12/20)

12

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably extensive. Exhibits very competent critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. Breadth and depth of knowledge. There are few misconceptions . (11/20)

11

3. COGNITIVE AND INTELLECTUAL



Sound critical evaluation and analysis of concepts. Is selective in the range of evidence used and synthesises rather than describes. Ability to devise arguments that show awareness of different stances, and use evidence convincingly, to support appropriate and valid judgements. (11/20)

11

4. PRACTICAL APPLICATION



A very good application of a range of established methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose appropriate solutions outside

12

the context in which they were first studied. Evidence of some creativity. (12/20)

5. TRANSFERABLE SKILLS



Can communicate professionally confidently and consistently in a suitable medium for the audience. Work is coherent, very fluent and is presented proficiently. Can work autonomously with initiative. Where relevant can work professionally within a team, showing leadership skills as appropriate, and meeting obligations. Demonstrates excellent skills for employment requiring the exercise of personal responsibility and decision-making and an appetite for further development. (14/20)

14