

1809799

by Thomas Grennan

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1. Executive Summary

The report investigates the control engineering theories for three of the widest used control systems in industry, these being Flow, Level and Temperature. Firstly, research was undertaken upon general control systems and then primarily focused on flow, temperature and level control systems and typical process control philosophies followed by engineers working on control systems. Further research was embarked on focused on PID tuning methods, specifically the Caldwell method and Ziegler-Nichols 'Ultimate Cycle Method' and 'Process Reaction Method'.

The process station was then investigated, the system was looked into in order to gain an understanding of its control systems and process, Piping and Instrumentation Diagrams (P&ID) were created in order to visually represent the system, these diagrams were also aided by explanations.

The first experimental task undertaken was the flow control system. A flow run was performed on the flow control system, an array of data was extracted from the PLC and was inserted into an excel spreadsheet. The spreadsheet was then imported into MATLAB in order to obtain a process reaction curve. Values were obtained from this reaction curve; these values were used within the Caldwell method in order to derive the systems transfer function in turn providing a better process reaction curve, using the transfer function as a guideline it was then fine-tuned to produce an ideal reaction curve. The fine-tuned values were entered as a transfer function into a Simulink model of the system and auto-tuned to produce ideal values for K_p , K_i and K_d . Using the original process reaction curve a different method of obtaining the PID values was used, this being the Ziegler-Nichols method. The tuned Simulink values were entered as the PID variables in the PLC and the flow system was run, these values then had final adjustments manually made using trial and error in order to produce the best response on the process station. Comparisons and critical analysis were undertaken comparing all of the various PID values obtained.

The second experimental task undertaken was the Level control system. This system was run on the process station in order to obtain a process reaction curve, this time being a ramp response due to the Level control system being a pure integrator. Using values from the reaction curve the gradients were calculated in order to derive the transfer function. The transfer function was entered into a Simulink model and autotuned. The autotuned values obtained for K_p and K_d were entered into the PID variables in the PLC and the system was run, Finally the autotuned values were adjusted to provide the best Level response.

The final experiment was almost identical to the Level experiment. This experiment was undertaken on the temperature control system section of the process station. This system was run on the process station in order to obtain a process reaction curve, this also producing a ramp response due to the Temperature control system also being a pure integrator. Using values from the reaction curve the gradients were calculated in order to derive the transfer function. The transfer function was entered into a Simulink model and autotuned. The autotuned values obtained for K_p and K_d were entered into the PID variables in the PLC and the system was run, Finally the autotuned values were adjusted to provide the best Temperature response.

A conclusion and evaluation were then written, critical analysis of the entirety of the report was undertaken comparing the how the research element benefited the experimental phases of the report, the significant outcomes of the report and how the report could have been improved as a whole.

2. Research and System Investigation

2.1 Research

A control system is a system of devices used in order to manage, control and regulate the behaviour and actions of control devices in order to achieve a desired result. This is achieved through engineered control loops which are designed in order to achieve an accurate outcome from a set-point. (electrical4u, 2020) Correctly cited

Process control systems consist of three main components, these are a controller, a measuring device, and a regulator. The controller's purpose is to compare the sensors recorded measurement against the pre-determined set-point value, if there is a difference or 'error' between these two values then the control system will initiate an action in order to reduce the error between the output and the set-point. Most applications within industry that require a control system will suffice with a single loop controller which monitors one measurement and one regulator, these can also be 'cascaded' to another controller if its value determines a second process. The measuring device is often a sensor, this sensors purpose is measuring a variable such as flow, level or temperature, an output from this sensor will send a signal via a transmitter to a controller. A regulator is a control element within the system, it acts as a slave to the controller and makes quick adjustments to reduce the error and produce an accurate output, Typical regulators are control valves and pumps. (Nldirect, 2020) Correctly cited

Control systems can be narrowed down into two sub-categories, Open loop and closed loop. Open loop control systems have no feedback from the output to the input, in this system the output is varied by altering the input. Open loop control systems seen in figure 1 are simple and easy to create, however, without feedback from a sensing element it means that external conditions will impact the output ultimately causing them to be unreliable and inaccurate.

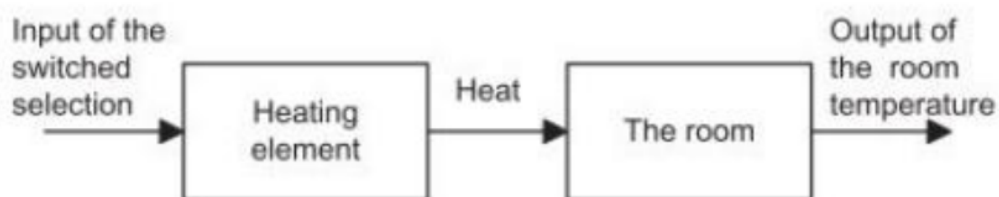


Figure 1 – Open Loop Control System Block Diagram (Bolton, 2015)

Correctly cited

Closed loop systems seen in figure 2 incorporate feedback into the system; therefore, the output is sent back to the input in order to control the output value, these systems are accurate, have higher sensitivity whilst providing stability (Engineers, 2021). Correctly cited

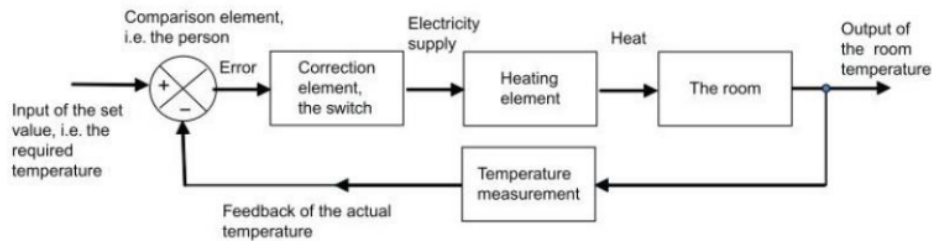


Figure 2 – Closed Loop System (Bolton, 2015)

Open and Closed loop control systems are compared in figure 3.

Open Loop Control System	Closed Loop Control System
Independent control action	Dependent control action
No feedback path	Feedback path
Non-feedback control system	Feedback control system
Can be designed easily	Cannot be designed easily
Manually controlled	Fully automated
Economical	Expensive
Inaccurate	Accurate

Figure 3 – Open vs Closed Loop Control Systems (TeachComputerScience, 2021)

Process controllers are components within the control system which take the error signal as an input and produce an output signal in order to modify the systems output to reduce the error. The most basic form of controller is the on-off device, this device turns on a correcting device when there is an error and turns it off when there is no error, this often incorporate a hysteresis to reduce the device constantly turning on and off. On-Off devices are highly limited and more sophisticated controllers are available (Bolton, 2015) Correctly cited

In order to provide better accuracy other controllers are used, these being Proportional, Integral and Derivative, these are explained in table 1 (Instruments, 2020). Correctly cited

Proportional vs Integral vs Derivative Control	
Proportional	The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The <i>proportional gain</i> (K_c) determines the ratio of output response to the error signal. For instance, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate. If K_c is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.
Integral	The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero.
Derivative	The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the <i>derivative time</i> (T_d) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (T_d), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable

Table 1 – Proportional vs Integral vs Derivative Control (Instruments, 2020)

This this table is an image, it would be better in the appendix

Controllers can be further categorised under three sub-categories, these being discrete, multi-step and continuous, these are explained in table 2 (Ahmed, 2006). Correctly cited

PID Controller Subcategories	
Discrete	Discrete controllers are controllers that have only two modes, these being on and off. An application where this controller is used is a hot water heater. When the temperature of the water in the tank falls below setpoint, the burner turns on. When the water in the tank reaches setpoint, the burner turns off. Because the water starts cooling again when the burner turns off, it is only a matter of time before the cycle begins again. This type of control doesn't actually hold the variable at setpoint, but keeps the variable within proximity of setpoint in what is known as a dead zone.
Continuous	Controllers automatically compare the value of the PV to the SP to determine if an error exists. If there is an error, the controller adjusts its output according to the parameters that have been set in the controller. The tuning parameters determine how much correction is needed, the time duration that the correction is needed and the speed at which it should be corrected.
Multistep	Multistep controllers are controllers that have at least one other possible position in addition to on and off. Multistep controllers operate similarly to discrete controllers, but as setpoint is approached, the multistep controller takes intermediate steps. Therefore, the oscillation around setpoint can be less dramatic when multistep controllers are employed than when discrete controllers are used.

Table 2 – PID Controller Subcategories

2.1.1 Flow Control

Flow control loops are considered as fast loops that quickly respond to changes. Due to this flow control equipment must have fast sampling and response times. Flow control systems are naturally at least 2nd order systems which require PID control in order to accurately keep a continuous flow rate which matches the set-point in order to achieve zero error. (Maplesoft, 2014) Correctly cited

Figure 4 shows a flow control system, this system uses a valve to control the flow of fluid inside the systems pipes, therefore the valves are the control element. The flow within the system is monitored by a flow sensor, available in the form of orifice, ultrasonic, turbine and more. A flow transmitter is used to send a signal of the flow rate back to the PID controller, this signal is compared with the set-point value. If the value is lower than the set-point then the valve will open more in order to allow larger flow, if the value is higher than the set-point then the valve will close to restrict flow. (Ranjith, 2017) Correctly cited

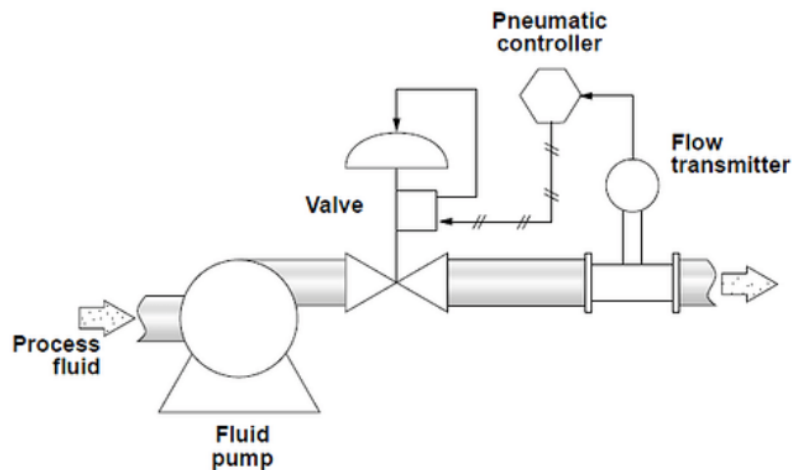


Figure 4 – Flow Control System Diagram (Ranjith, 2017)

2.1.2 Level Control

Level control systems are used when the amount of liquid within a system needs to be controlled. The purpose of these systems is to effectively control and maintain the level of liquid within a system. The systems controller will create a control signal which will be read by an actuator and is sent to the plant in order to perform the necessary action (Evans, 2020). Table 3 displays the required components of a Level control system.

Correctly cited

Level Control System Components	
Component	Purpose
Fluid Tank	Used to hold the desired amount of fluid
Measurement system	Senses the level of the fluid inside the tank.
Controller	The controller is used to maintain the desired level by starting and stopping the pump when gets information by the measurement system. This can be in the form of P, PI, PD or PID.
Pump	The water from the source is fed to the tank through the pump when actuated by the controller.

Table 3 – Level System Components

A typical level control system is seen in figure 5.

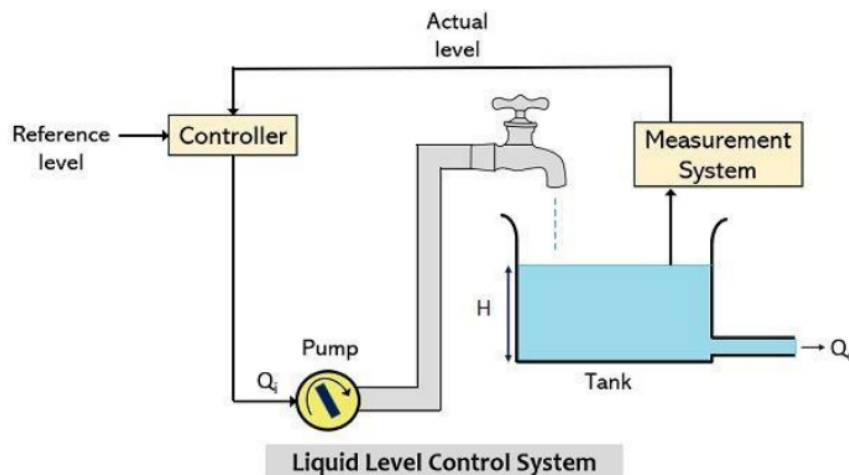


Figure 5 – Level Control System Diagram (electronicscoach, 2021)

Various methods of level control systems are seen in table 4.

Level Control System Methods	
Method	Operation
Float operated types	a float rises and falls according to the change in liquid level and operates switches at predetermined points in the range.
Steel rope capacitance types	a flexible steel rope is suspended in the liquid, and the change in capacitance is measured relative to the change in water level
Ultrasonic types	a high frequency acoustic pulse is directed down from a transducer to the surface of the medium being measured and, by knowing the temperature and speed of sound in air, the time it takes for the pulse to rebound to the sensor is used to determine the level.
Hydrostatic types	a pressure transmitter is used to measure the pressure difference between the confined hydrostatic pressure of the liquid head above the sensor and the outside atmospheric pressure. Changes in pressure are converted into a 4-20 mA output signal relative to the head difference.

Table 4 – Level Control System Methods (electronicscoach, 2021)

A block diagram for a level control system is seen in figure 6. The desired level set-point is set at the input. A controller such as a PID controller will control the speed at which the water is pumped into the tank, the tank has a sensor which determines its level, a signal from this sensor is fed back to the comparison element which will monitor the error between the actual level and the set-point and adjusting the system accordingly. (Haugen, 2014)

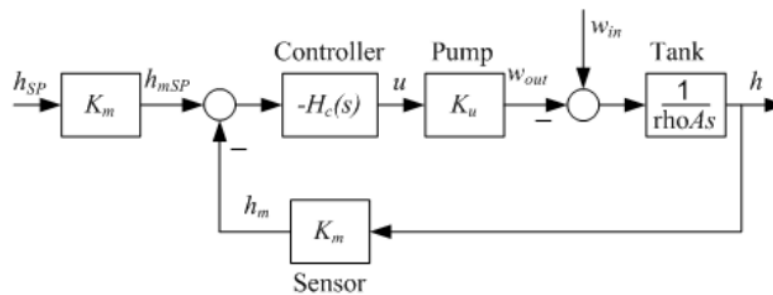


Figure 6 – Level Control System Block Diagram (Haugen, 2014)

2.1.3 Temperature Control

Temperature control systems are critical in applications where the temperature is needed to be kept stable (Controls, 2021). Temperature control systems can be categorised into two sections: Open loop and Closed loop, Open loop systems are basic and constantly applying the set-point to the system with no feedback control to reduce or heat the temperature when needed (electronics-tutorials, 2019). Closed loop systems offer greater accuracy and reliability, the output temperature is constantly monitored by a sensor which is sent back to summing junction which will send signals to the controller in order to achieve the desired output, this is visually seen in figure 7 (electronics-tutorials, 2019)

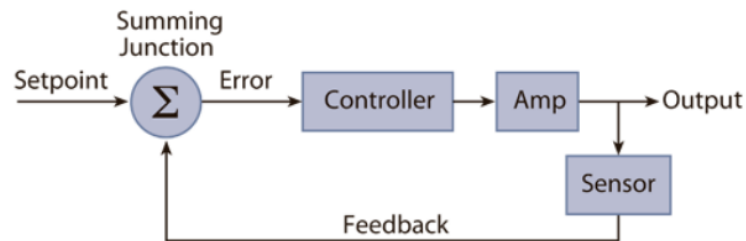


Figure 7 – Temperature Control System Block Diagram (electronics-tutorials, 2019)

This diagram is not specific to temperature and could be for any control loop

Due to the long-time taken to change the temperature of a process fluid, temperature control systems are often quite slow. A method of speeding this system up is through the use of a feedforward system. Typical temperature sensors used in these systems are RTDs and thermocouples. A typical temperature control system is seen in figure 8 (Ahmed, 2006).

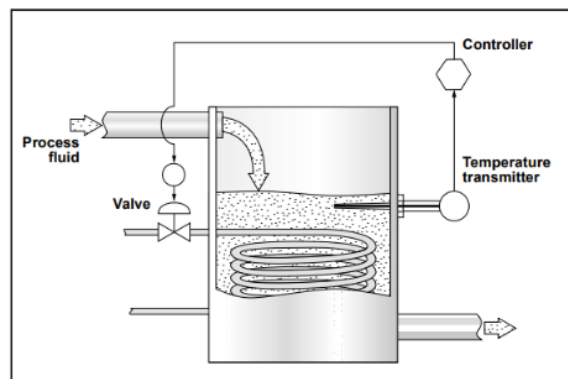


Figure 8 – Temperature Control System Diagram (Ahmed, 2006)

The most accurate method of temperature control is through a PID controller. This allows for smooth proportional control, automatic offset adjustment through the integral control and the derivative control which monitors fast response to external disturbances which can affect the process (Omron, 2018)

2.1.4 Process Control Philosophies

A Proportional Integral Derivative (PID) controller is an instrument that is used within industrial control applications, this controller is used to regulate processes such as flow, level and temperature. PID controllers use a closed-loop feedback circuit in order to control the process variable in order to achieve an output that is as close to the set-point as possible (Omega, 2020)

A PID controller includes a proportional (P) element, an integral (I) element and a derivative (D) element. $u(t)$ is the controller's output, therefore the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(t) dT + K_d \frac{d}{dt} e(t)$$

Whereby:

P_{out} : Proportional term of output
 K_p : Proportional gain, a tuning parameter
 K_i : Integral gain, a tuning parameter
 K_d : Derivative gain, a tuning parameter
 e : Error = $SP - PV$
 t : Time or instantaneous time (the present)
 MV : Manipulated variable

Figure 9 depicts a typical block diagram for a control system, whereby a PID controller is typically used.

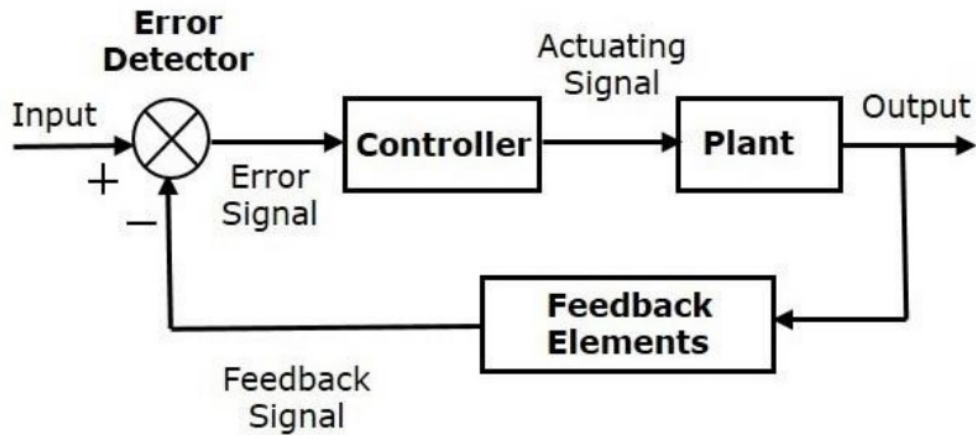


Figure 9: PID Control System (Maplesoft, 2014)

2.1.6 Methods of PID Tuning

Tuning is defined as the process of selecting the best controller settings for that specific applications, for tuning a PID controller this means choosing values for the three constants K_p , K_i and K_d . Bolton states that the most basic method of tuning is “Step 1 - Set gains for P, I and D to zero, Step – 2 Increase the gain of P until the disturbance response is a steady oscillation, Step 3 - Increase the value of D until the oscillation disappears, Step 4 - Repeat steps 2 and 3 until increasing the gain value of D does not stop the oscillating, Step 5 - Set the values of P and D to the stable values obtained and finally Step 6 - Increase the gain of I until the set-point is met with no oscillations” (2015, p. 112). Correctly cited

John Ziegler and Nathaniel Nichols were American Control Engineers, both engineers made the assumption that when a control system is in open loop it behaves like a first-order system with a time delay, from this theory they developed parameters for superlative performance. Correctly cited Franklin states that “Ziegler and Nichols recognized that the step-responses of a large number of process control systems exhibit a process reaction curve” (2014, p. 5), From their studies Ziegler and Nichols developed two types of PID tuning methods, The “Process Reaction Method” and the “Ultimate Cycle Method”

For the ‘Process Reaction Method’ the process control loop of the plant is opened between the correction element and the controller in open-loop mode, with this open circuit no control action will transpire. A small test input known as a signal step is applied to the correction element in order to determine the response of the controlled variable, this step is defined as P which is the percentage change in the correction unit. From this a graph will plotted of the measured variable against time, this is the process reaction curve (Figure 10) which is defined as the percentage of full-scale range (Bolton, 2019).

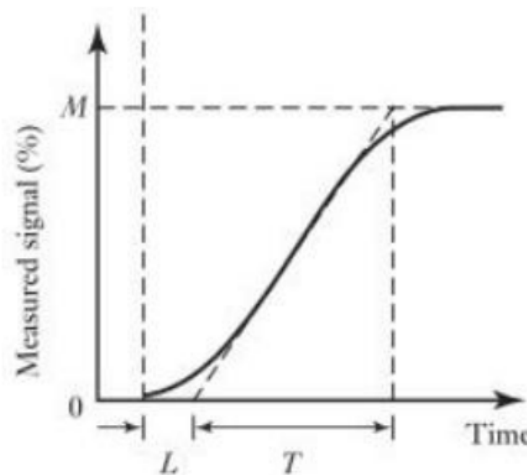


Figure 10 - The Process Reaction Graph

A tangent is drawn in order to give the graphs maximum gradient, the maximum gradient ' R ' is determined as ' M/T ', The time between the test signal starting and the point of intersection along the time axis is the transport lag (L). Figure 11 shows the table developed by Ziegler and Nichols to find the values of K_p , K_i and K_d for control settings based on the controller type and values of P , L and R , these values will then be inserted back into the control system.

Control mode	K_p	T_i	T_D
P	P/RL		
PI	$0.9P/RL$	$3.33L$	
PID	$1.2P/RL$	$2L$	$0.5L$

Figure 11 – Parameters for the Process Reaction Method (Bolton, 2015)

Another PID tuning method is the 'Ultimate Cycle Method', for this tuning method values of K_i and K_d are lowered to their minimum values, the value of K_p is set to a low value and is slowly increased whilst minor disturbances are applied to the system in order to achieve steady oscillations. Bolton states that "The critical value of the proportional constant K_{pc} at which this occurs is noted along with measuring the periodic time of oscillations as T_c " (2015, p. 66). Ziegler-Nichols developed a table to mathematical table in order to calculate the values of K_p , K_i and K_d by entering the values of K_{pc} and T_c into their respective equations, Figure 12 shows the parameters derived by Ziegler-Nichols for this method. (Solutions, 2021)

Control mode	K_p	T_i	T_D
P	$0.5K_{pc}$		
PI	$0.45K_{pc}$	$T_c/1.2$	
PID	$0.6K_{pc}$	$T_c/2.0$	$T_c/8$

Figure 12 - Parameters for the Ultimate Cycle Method (Bolton, 2015)

2.2 System Investigation

The Computer Integrated Manufacturing (CIM) system consists of various stations, a P&ID diagram of this system is seen in appendix 9.1. TC535 is the control loop for the flow of water into tank B1, TC511 controls the temperature of the water in tank B1 and TC541 controls the water level within tank B1.

The flow control loop utilises a flow controller (FC535) which produces a control variable, the CV is fed into the pump amplifier (LY541). The flow transmitter (FT535) gives the system its process variable whilst taking a flow measurement, a signal is sent back to FC535 in order to increase or decrease the pump speed depending on the water level in tank B1, the level of the tank is determined by the level switches LS542 and LS543, the P&ID diagram for FC535 is seen in appendix 9.1.

Appendix 9.1 displays the P&ID diagram of the temperature control loop; the temperature control loop (TC511) monitors the temperature of the water in tank B1. This loop uses a temperature transmitter (TT511) to send signals to the temperature controller (TC511) which controls the state of the tanks heating element depending on what the water temperature is and what is required, a solid-state relay is used to enable the heater. If the water is too hot the pump amplifier (LY541) will pump cold water into the tank or the cooling fan is enabled. A safety interlock is incorporated so that there has to be sufficient water in the tank in order to heat it.

The level control loop monitors the water level in tank B1, this is controlled by the level controller (LC541), the water level is sensed by the tanks limit switches and the level transmitter (LT541) which monitors the differential pressure. When tank B1 is full the solenoid of the drain valve is energised opening the drain valve (V500) and draining the water into tank B0. If the water level is too low tank B1 is filled by the amplifier pump (LY541), the P&ID diagram for this loop is seen in appendix 9.1.

3. Flow Control System

3.1 Process Reaction Method

A flow run was performed on the flow control system, Using TIA portal an array of dynamic data was obtained, this data was then copied over to an excel spreadsheet. This spreadsheet was then imported into MATLAB combined with a written code for the program, seen in appendix 9.2 along with further explanation. The process reaction response is seen in figure 13.

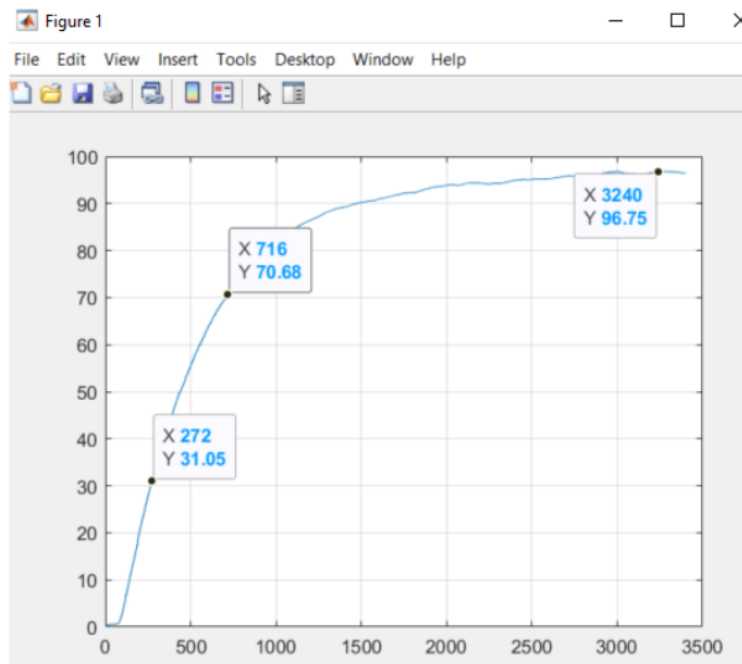


Figure 13 – Flow Control System Process Reaction Curve

Figure 13 shows data points applied to process reaction response; the values of these data points are used within 'Caldwell Method' in order to calculate the transfer function of the model. These calculations are seen in appendix 9.3.

From the calculations in appendix 9.3, the transfer function below is derived:

$$G(s) = \frac{25.09}{s^2 + 13.68s + 25.1}$$

Figure 14 shows the original process reaction curve in blue, compared to the curve obtained from the Caldwell method in red and then the response by fine tuning the transfer function is seen in yellow, this produced the most accurate representation of the process.

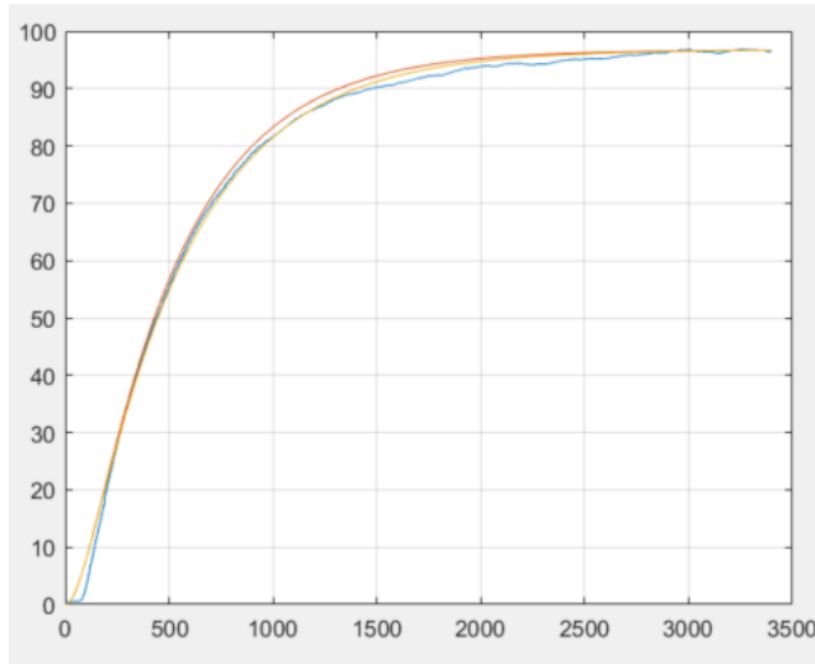


Figure 14 – Flow Control System Original vs Caldwell Method vs Fine Tuning

A Simulink model was then created (Figure 15), this allows viewing of the process reaction curve within a closed loop circuit with a PID controller and variable set-points. The values inserted into the transfer function within the closed-loop circuit are the same as the adjusted MATLAB transfer function as a starting point. The model has a transport delay which mimics the delay between the PLC telling the pump to start and the flow sensor monitoring the flow of water, from this model values of P, I and D are obtained which can be used for the practical testing. A saturation of 1 is added after the transport delay to match the pumps duty cycle.

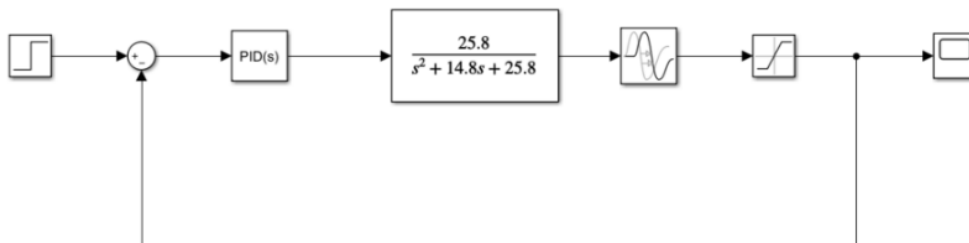


Figure 15 – Flow Control System, Simulink Model

The PID controller within the model was then autotuned using its autotune function as seen in figure 16. It is clear to see that the tuned response provided a response with a reduction in overshoot by over 10% after auto-tuning, however, the rise and settling time have marginally increased.

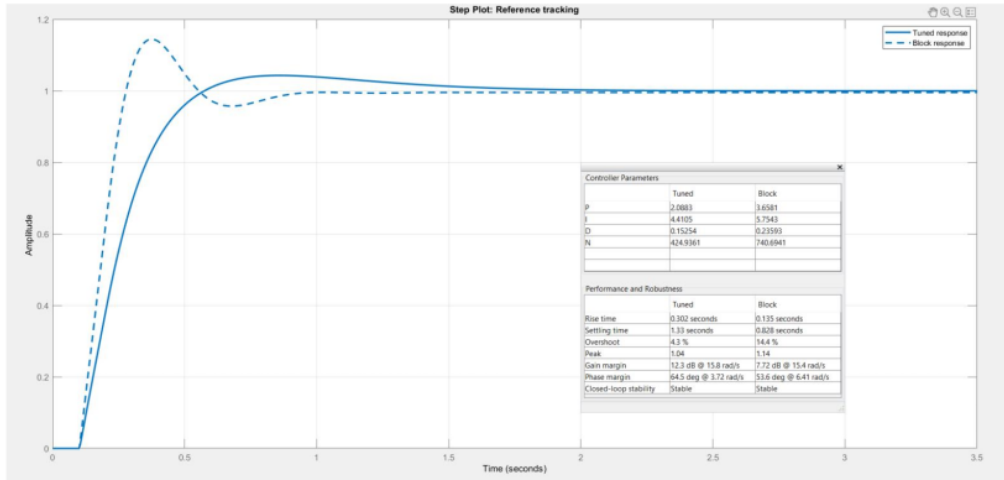


Figure 16 – Flow Control System Simulink Model Response

Table 5 displays the PID values obtained from the Simulink model.

Flow Control System: PID Values Tuned vs Untuned			
	K_P	K_I	K_D
Untuned Values	3.6581	5.7543	0.23593
Tuned Values	2.0883	4.4105	0.1524

Table 5 - Flow Control System: PID Values Tuned vs Untuned

The Simulink model was then simulated and viewed using the scope device within Multism, it created a quick response to reach steady state with no overshoot or oscillations (Figure 17).

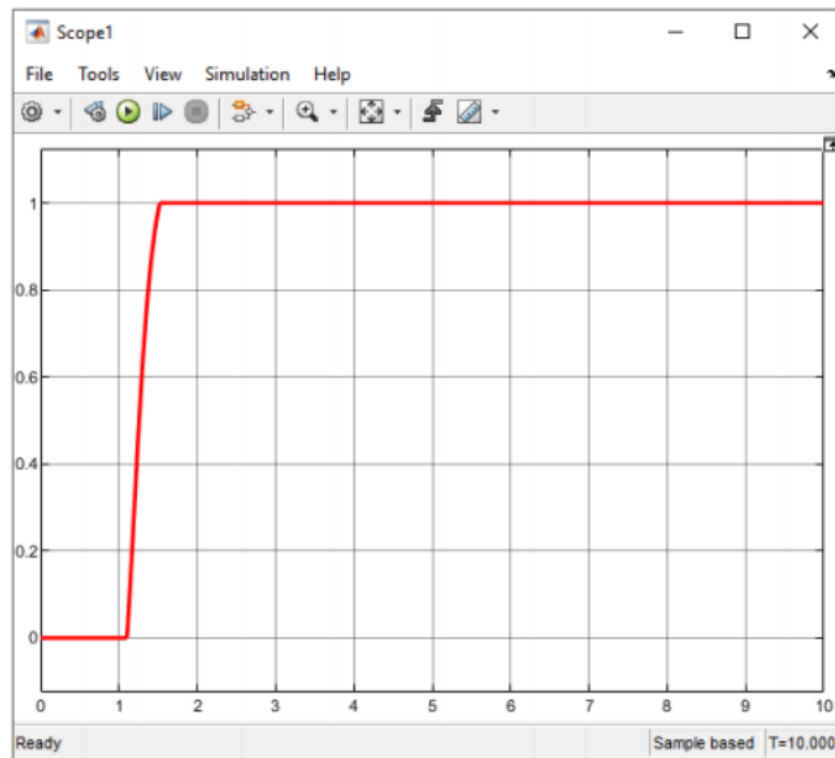


Figure 17 - Flow Control System Simulink Model Scope Response

3.2 Ziegler-Nichols Method

The Flow process system can also be tuned using the Ziegler-Nichols method. The original process reaction curve is utilised, Values for the set-point change (ΔC) and the output change (ΔY) are needed. In this case $\Delta C = 100$ and $\Delta Y = 96.75$. A tangent line is drawn at the steepest point of the curve, the points of intersection between the 0 and 100% points determines the values for 'L' and 'T', these are needed for the calculations in order to obtain the PID values for the system, these are seen in appendix 9.4.

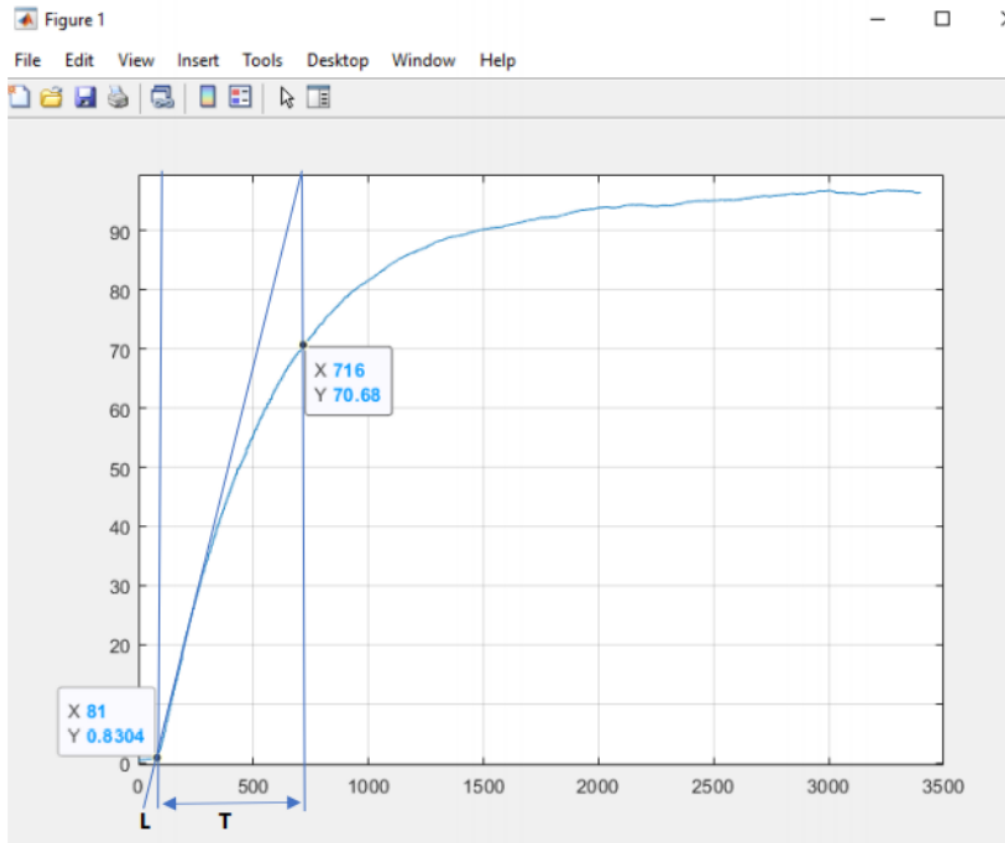


Figure 18 – Obtaining the values needed from the process reaction curve for the Ziegler-Nichols method

Values obtained for K_p , K_i and K_d from the equations seen in appendix 9.4 are displayed in table 6.

Flow Control System: Ziegler-Nichols Values		
K_p	K_i	K_d
9.723	60.019	0.394

Table 6 – Calculated PID values for Ziegler-Nichols method

The calculated Ziegler-Nichols values seen in table 6 were entered as the PID values within Simulink. Figure 19 displays the PID response.

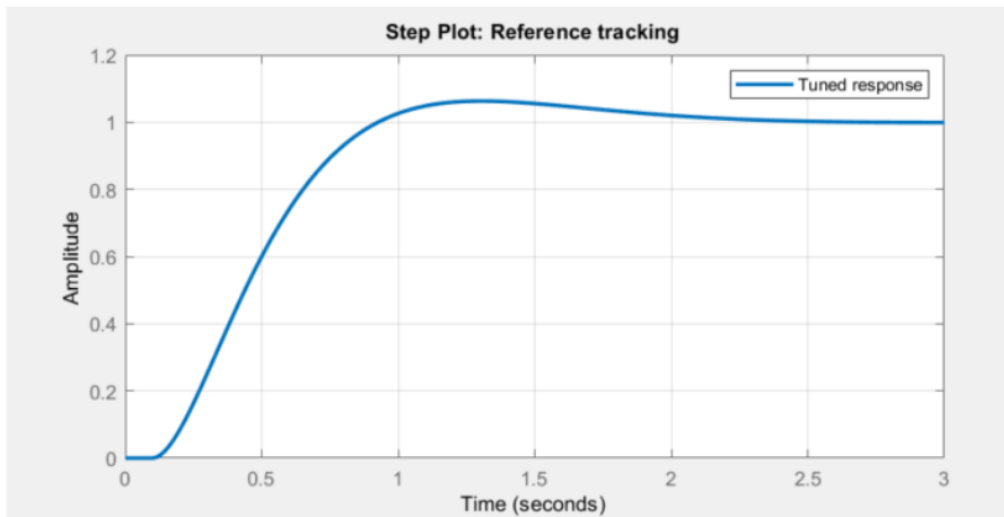


Figure 19 – Ziegler-Nichols Simulink Response

3.3 Analysis and Conclusions

Table 7 displays the results for K_P , K_I and K_D .

Flow Control System: Caldwell vs Autotune vs Ziegler-Nichols			
	K_P	K_I	K_D
Untuned Response (Caldwell)	3.6581	5.7543	0.23593
Simulink Autotune	2.0883	4.4105	0.1524
Ziegler-Nichols	9.723	60.019	0.394
Final Adjustment	0.900	0.0073	13.7

Table 7 – Flow Control System Comparison of PID values

It is clearly seen when comparing the 4 different values that there are differences between the ideal practical response and the three theoretical values. There are small discrepancies between the untuned Simulink response obtained through the Caldwell method and the autotuned values, this is expected as the values have been tuned to produce the best response within Simulink. The Ziegler-Nichols method produced different values compared to the Caldwell response, Due to the global pandemic these values were not able to be tested on the process station. However, when these values were entered into the Simulink system it produced a slower response with a larger overshoot than the Caldwell responses (Figure 19).

The Simulink autotuned response has the closest values to the final adjustment values from the HMI, this response produced the best results with the least amount of error at -0.14 as seen in appendix 9.7. The scope response of the Simulink model seen in figure 17 produced an ideal response with no oscillations or overshoot, which would be hard to replicate in a real-world scenario.

4. Level Control System

A Level run was performed on the process station. Values obtained from the HMI were used to calculate the gradient of the response, this is possible as the response is expected to be of a 'ramp response' which produces a steadily increasing linear response. The process reaction curve produced on the HMI produced the gradient values seen in table 8, Appendix 9.5 shows the transfer function calculated from the gradient values.

Level Gradient HMI Values		
X	$X_1 = 44$	$X_2 = 215$
Y	$Y_1 = 1.911$	$Y_2 = 19.526$

Table 8 – Level Control System Gradient Values from HMI

Figure 20 shows the Simulink model of the Level control system with a PD controller, cascaded with the flow control system.

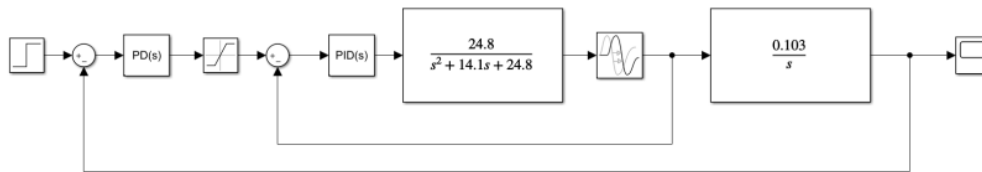


Figure 20 – Level Control System Simulink PID Model

The Simulink model is tuned using Simulink's autotune feature, Figure 21 displays the tuned response (dashed lines) compared to the original block response (solid line). The tuned response provided a quicker response, however, as a result it caused 6.8% overshoot which is not ideal for this system.

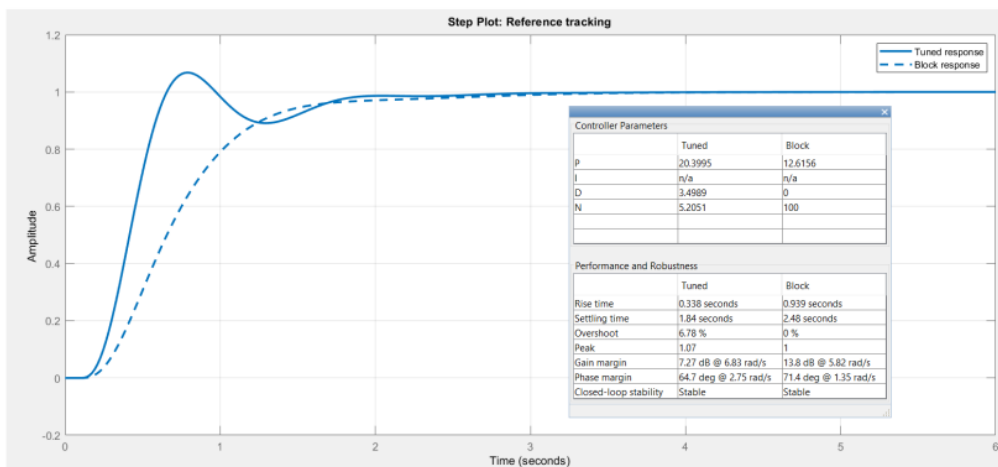


Figure 21 – Level Control System Simulink Responses

Table 9 shows the values obtained for K_p , K_I and K_D from the untuned and tuned model response. This tuned response for K_p and K_D is used as the starting values in the PLC.

Level Control System: PID Values Tuned vs Untuned			
	K_p	K_I	K_D
Untuned Values	12.6156	N/A	0
Tuned Values	20.3995	N/A	3.4989

Table 9 - Level Control System: PID Values Tuned vs Untuned

The level set-point was set to 20cm, a simulation was then run within Simulink using the tuned value obtained. The response is seen in figure 22, the response seen displays the ideal response for this control system.

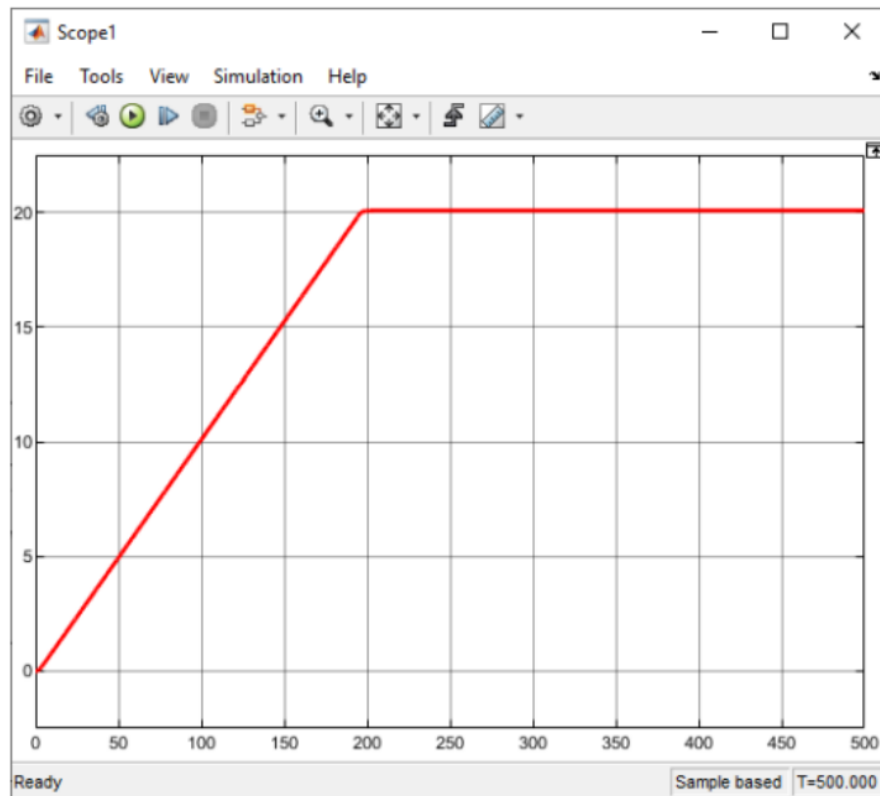


Figure 22 – Level Control System Scope Response

Level Control System: Relationship between the Value of K_p and SSE			
Temperature Run	Value of K_p	Value of K_D	Steady State Error
Untuned	12.6156	0	1.19
Simulink Tuned Value	20.3995	3.4989	0.43
HMI Tuned Value	50	10	0.31

Table 10 - Level Control System: Relationship between the Value of K_p and SSE

When the K_p value was set as the untuned value of 12.6156 with a K_D value of 0 as obtained from the untuned Simulink. At these values the water takes a long period to reach a value near the set-point, the process response is not completely linear and displays a steady state error of 1.19.

Using Simulink's autotuned values whereby K_p is 20.3995 and $K_D = 3.4989$, when these values are written to the PID variables within the PLC it produced a more linear response and reduced the steady state error to 0.43 with a faster response time.

Using the autotune values as a basis for trial and error, the variables of K_p and K_D were modified to a K_p value of 50 and a K_D value of 10, this produced the most comparable response to the ideal Simulink response seen in figure 22, this also produced the smallest steady state error. Evidence of the experimental response can be seen in appendix 9.8.

5. Temperature Control System

A temperature run was performed on the CIM system. Values obtained from the HMI were used to calculate the gradient of the response. The process reaction curve produced on the HMI produced the gradient values seen in table 11, Appendix 9.6 shows the transfer function calculated from the gradient values.

Temperature Gradient HMI Values		
X	$X_1 = 157$	$X_2 = 788$
Y	$Y_1 = 18.265$	$Y_2 = 43.55$

Table 11 - Temperature Control System: PID Values Tuned vs Untuned

The Simulink model of the temperature control system is seen in figure 23.

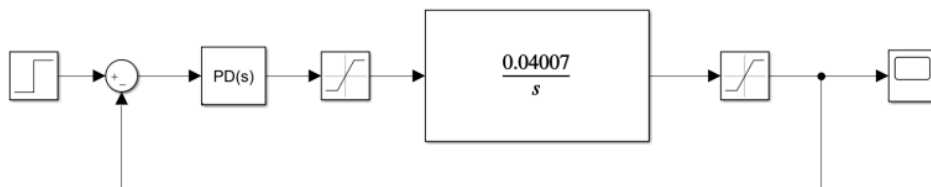


Figure 23 - Temperature Control System Simulink PID Model

This model was tuned using the autotune function, Figure 24 shows the comparison between the untuned 'block response' in the dashed line and the tuned response seen in the solid line. The tuned response achieved is ideal, it produced 0% overshoot and reduced the settling time to 3.91 seconds when compared to the untuned settling time of 7.3 seconds.

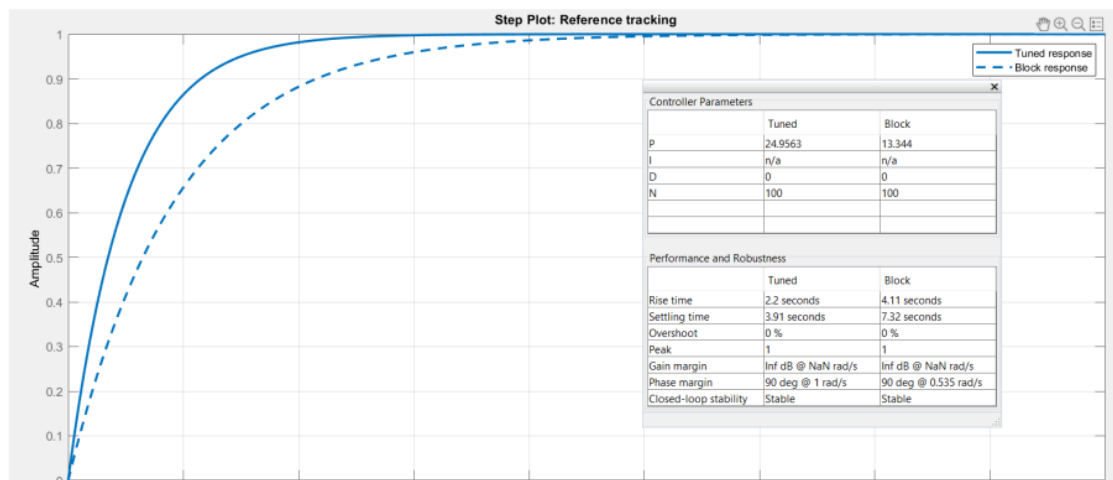


Figure 24 - Temperature Control System Simulink Responses

Table 12 shows the values obtained for K_p , K_I and K_D from the untuned and tuned model response. This tuned response for K_p is used as the value for the variable ' K_p ' in the PLC.

Temperature Control System: PID Values Tuned vs Untuned			
	K_p	K_I	K_D
Untuned Values	24.96	N/A	0
Tuned Values	13.344	N/A	0

Table 12 - Temperature Control System: PID Values Tuned vs Untuned

The temperature set-point was set to 50°C, a simulation was then run within Simulink using the tuned value obtained. The response is seen in figure 25, this shows an ideal approximated response of how the control system will respond.

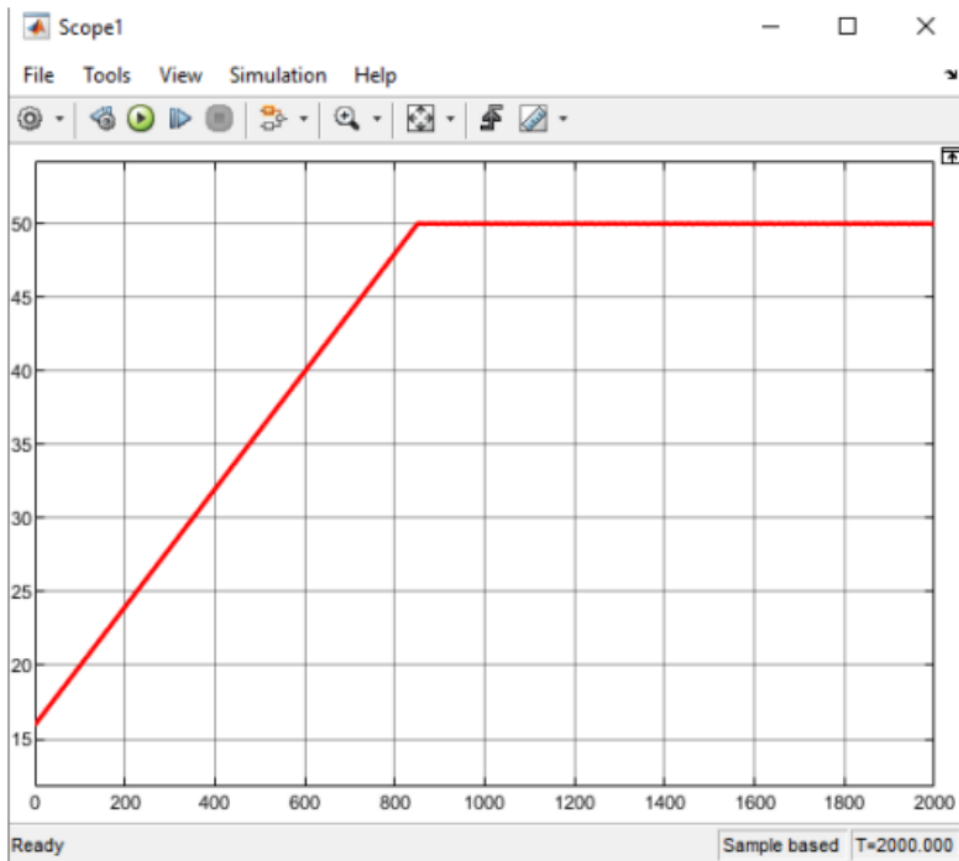


Figure 25 - Temperature Control System Scope Response

A temperature run was performed on the process station, the temperature set-point was set at 50°C and various values of K_p were used (Table 13).

Temperature Control System: Relationship between the Value of K_p and SSE		
Temperature Run	Value of K_p	Steady State Error
Simulink Autotuned	13.344	0.55
HMI Tuning Stage 1	35	0.05
HMI Tuning Stage 2	50	0.32

Table 13 - Temperature Control System: Relationship between the Value of K_p and SSE

Firstly, the K_p value was set at 13.344 as obtained from the autotuned Simulink. At this value the water took a long period to reach a value near the set-point, this response was rough with some oscillations, it is seen that this K_p is not ideal in this scenario.

The value of K_p was then increased to 35, this produced a more linear response as seen in the simulation, taking roughly the same time to reach the set-point. At this value of K_p its steady-state value was seen to be very accurate to the 50°C setpoint with a minor error of 0.05.

K_p was then increased to 50, this also produced a good response, however there were more oscillations than the response with K_p value of 35, the steady-state value also produced a larger error, from this it is seen that the HMI tuning stage 1 values produced the best result. Evidence of these practical's are seen in appendix 9.9.

6. Conclusions and Recommendations

As a whole, the research and experiments undertaken within this report were successful. The research undertaken set a solid basis of which the experiments were built upon, covering key aspects which directly related to the experiments. Key principles on the experimental control systems and methods of PID tuning laid the foundations of knowledge in order to provide a good understanding of the report experiments.

The experimental procedures provided experience and understanding of control system modelling and analysis. In terms of the flow control system, it was seen that the best response was formed from the 'Caldwell Method' PID values which were then auto-tuned in Simulink and fine-tuned to produce a best response with quick response times and minimal error. The Ziegler-Nichols method also produced a reasonable response which could have been improved through fine-tuning.

The tuning methods for the Level and Temperature control systems was less technical than the flow system due to these systems being integrators producing a ramp response. Mathematical calculations were derived to produce the systems transfer functions which were then entered into the Simulink system and auto-tuned to produce values for K_p , K_i and K_d . These values were then entered into the variables in the PLC and the systems were run, fine-tuning of these values were performed and reliable results were obtained proving the legitimacy of this tuning method.

Key experience of control system modelling was developed within the Simulink package and the importance of the control system components that are connected to the transfer function to produce the full system.

However, the experimental procedures did not produce the best possible outcomes. As a recommendation more time could have been focused directly on fine-tuning the PID values on the process station would have produced an optimal system. The flow control system could have been further explored by using the values obtained for K_p , K_i and K_d in the Ziegler-Nichols model within the flow system in order to see its performance. The process could have been improved with a linear pump to match the system replacing the current pump. Due to the global pandemic limited time was available for the experimental procedures and no recommendations could be brought to fruition.

7. Team Working

Due to the global pandemic team working was limited, All HSE guidelines were followed and a safe working environment was provided by the lecturer when performing experimental activities. The authors role was to derive the calculations obtained from the control system and to produce the Simulink models of the systems.

Group work was limited due to the local lockdown restricting class-based learning, Weekly meetings were held over google meet in order to discuss the tasks, this being the safest and most effective method of group-based learning.

8. Works Cited

Correct method of

Wide Range of

Bolton, W., 2015. Instrumentation and Control Systems. In: *Controllers*. s.l.:Newnes, p. 99.

Bolton, W., 2015. Instrumentation and Control Systems. In: Newnes, ed. *Control Systems*. s.l.:s.n., p. 84.

Bolton, W., 2019. Mechatronics. In: *Electronic Control Systems in Mechanical and Electrical Engineering*. s.l.:Pearson Education, p. 564.

Controls, D. I., 2021. *Why do we need temperature controllers?*. [Online]
Available at: <https://www.instrumart.com/pages/283/temperature-controller-basics-handbook>
[Accessed 08 03 2021].

electrical4u, 2020. *Control Systems: What Are They? (Open-Loop & Closed-Loop Control System Examples)*. [Online]
Available at: <https://www.electrical4u.com/control-system-closed-loop-open-loop-control-system/>
[Accessed 08 03 2021].

electronicscoach, 2021. *Liquid Level Control System*. [Online]
Available at: <https://electronicscoach.com/liquid-level-control-system.html>
[Accessed 08 03 2021].

electronics-tutorials, 2019. *Closed-loop Systems*. [Online]
Available at: <https://www.electronics-tutorials.ws/systems/closed-loop-system.html>
[Accessed 03 08 2021].

electronics-tutorials, 2019. *Open-loop System*. [Online]
Available at: <https://www.electronics-tutorials.ws/systems/open-loop-system.html>
[Accessed 08 03 2021].

Engineers, I. o. C., 2021. *Electrical control systems*. [Online]
Available at: https://www.designingbuildings.co.uk/wiki/Electrical_control_systems
[Accessed 08 03 2021].

Evans, P., 2020. *Liquid Level Switches Explained*. [Online]
Available at: <https://theengineeringmindset.com/liquid-level-switches-explained/>
[Accessed 08 03 2021].

Franklin, G. F., 2014. Feedback control of dynamic systems. In: s.l.:Pearson Education.

Haugen, F., 2014. *LIQUID LEVEL CONTROL OF BUFFER TANK*. [Online]
Available at: http://techteach.no/kybsim/buffer_tank/index.php
[Accessed 08 03 2021].

Instruments, N., 2020. *PID Theory Explained*. [Online]
Available at: <https://www.ni.com/en-gb/innovations/white-papers/06/pid-theory-explained.html>
[Accessed 08 03 2021].

Maplesoft, 2014. *PID Control*. [Online]
Available at:
https://www.maplesoft.com/content/EngineeringFundamentals/12/MapleDocument_12/PID%20Control.pdf
[Accessed 08 03 2021].

Nldirect, 2020. *Process control systems for energy efficiency*. [Online]
Available at: <https://www.nibusinessinfo.co.uk/content/how-process-control-systems-work>
[Accessed 08 03 2021].

Omega, 2020. *What is a PID Controller?*. [Online]
Available at: <https://www.omega.co.uk/prodinfo/pid-controllers.html>
[Accessed 2021].

Omron, 2018. *Temperature Controllers*. [Online]
Available at: <https://www.ia.omron.com/support/guide/53/introduction.html>
[Accessed 08 03 2021].

Ranjith, S., 2017. *Flow Control Loop Basics*. [Online]
Available at: <https://forumautomation.com/t/flow-control-loop-basics/2708>
[Accessed 08 03 2021].

Solutions, D. C., 2021. *PID Control*. [Online]
Available at: <https://www.pid-tuner.com/pid-control/>
[Accessed 08 03 2021].

TeachComputerScience, 2021. *Control Systems*. [Online]
Available at: <https://teachcomputerscience.com/control-systems/>
[Accessed 08 03 2021].

9. Appendix

9.1 – P&ID Diagrams of the Process Station

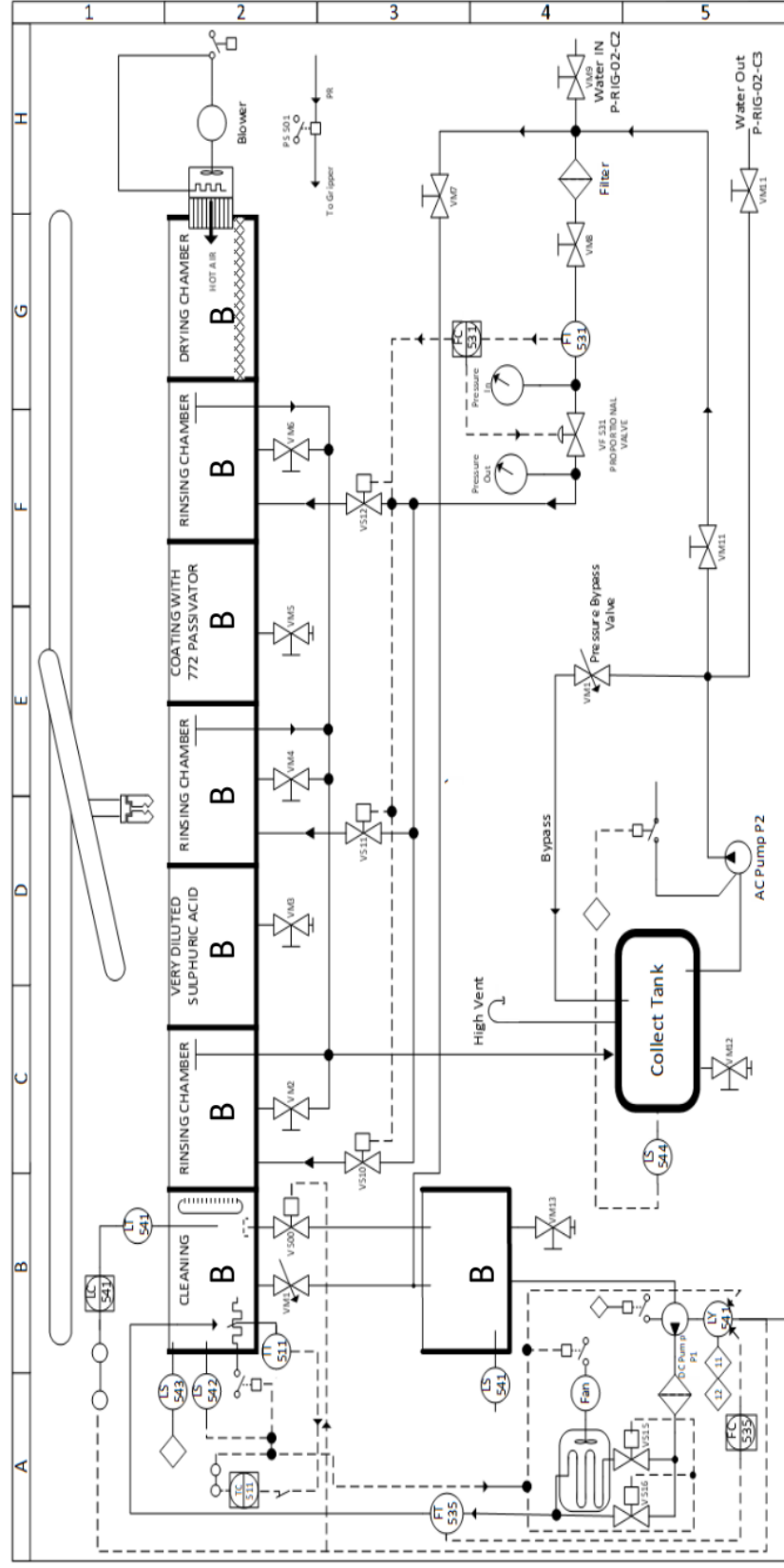


Figure 26 – Process Station P&ID Diagram

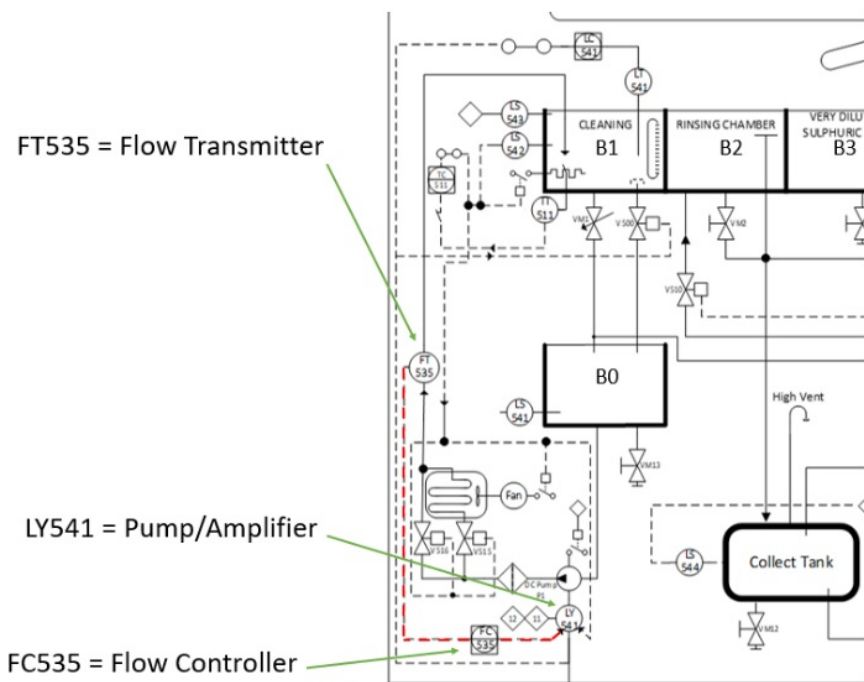


Figure 28 – Flow Control System P&ID

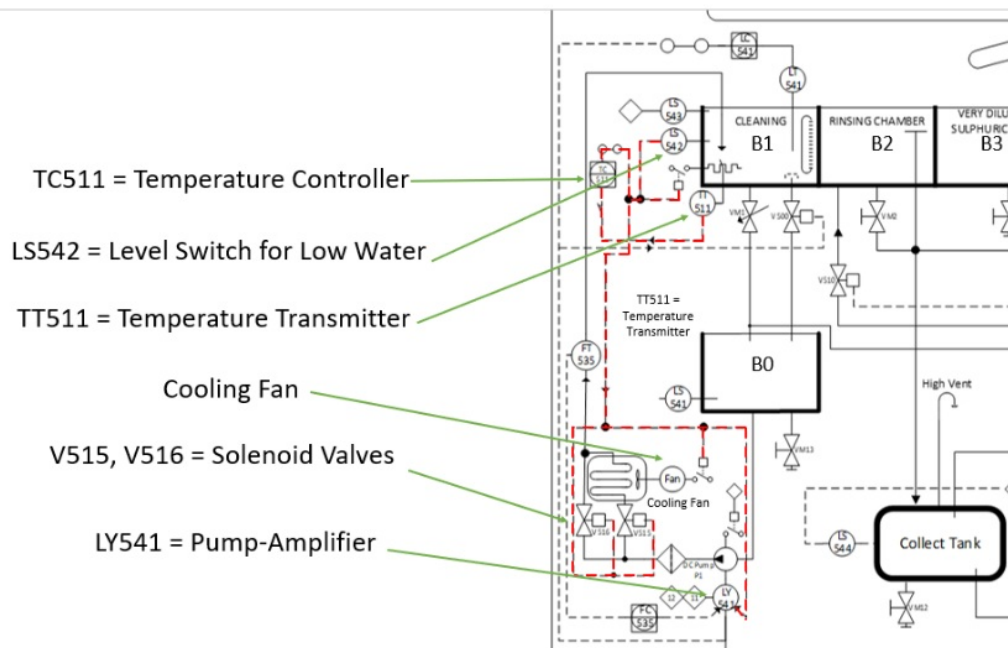


Figure 27 - Temperature Control System P&ID

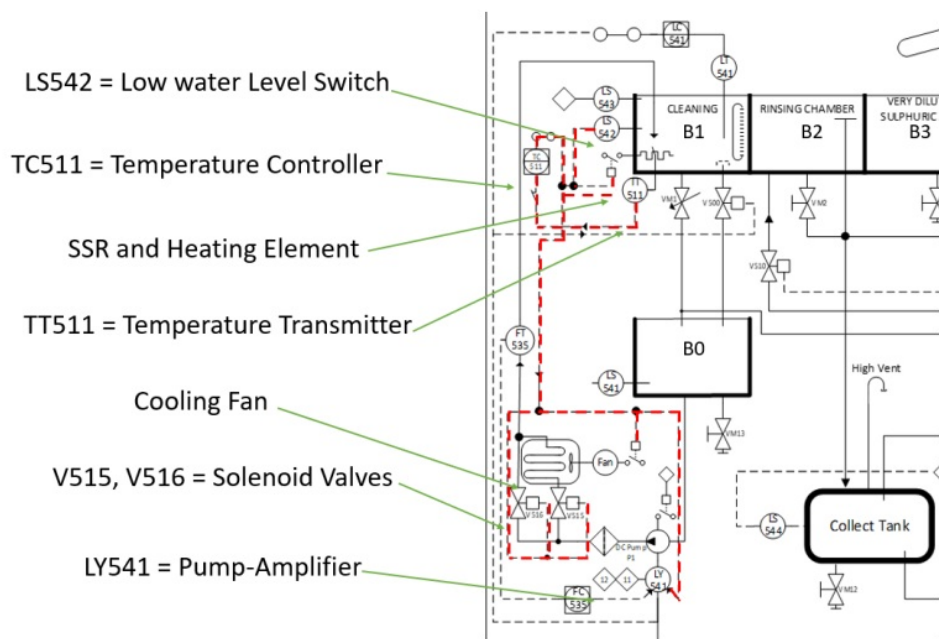


Figure 30 - Temperature Control System P&ID Continued

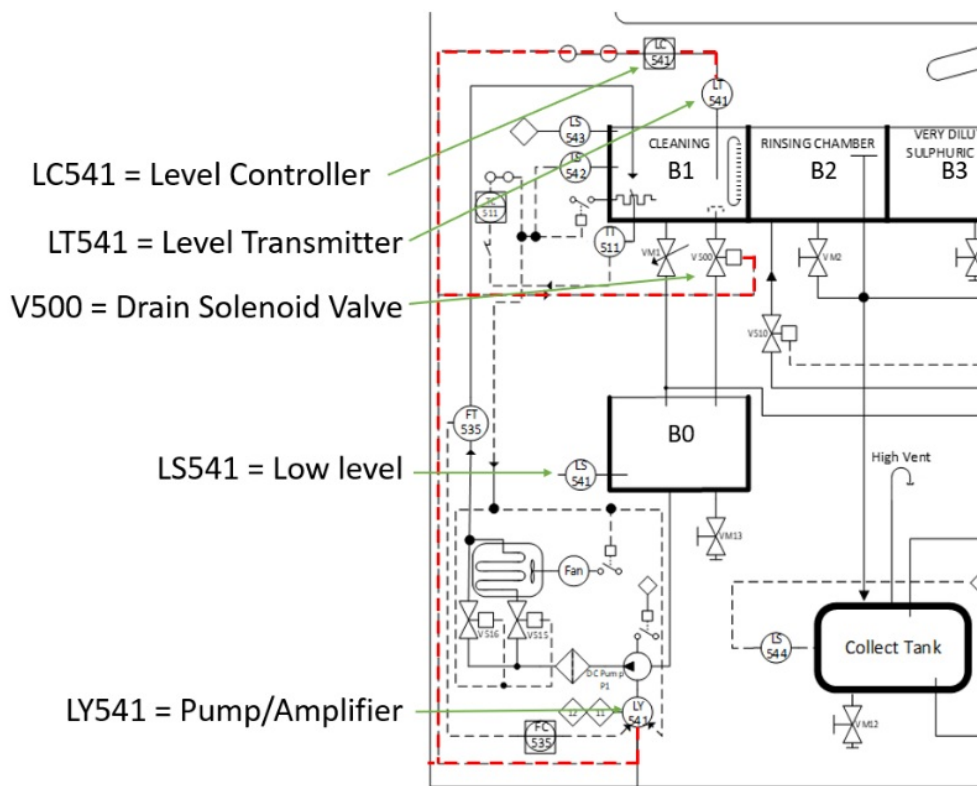
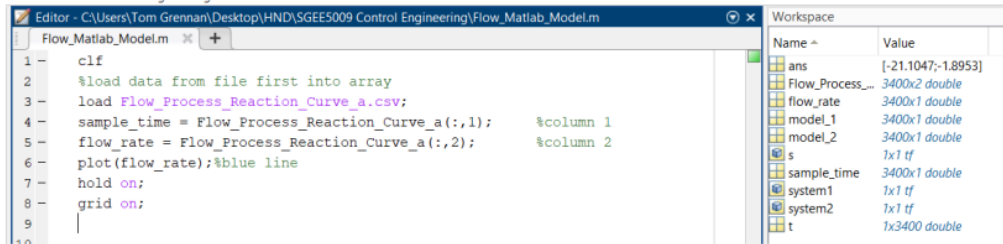


Figure 29 - Level Control System P&ID

9.2 – Flow Control System



The image shows a MATLAB Editor window with a script named 'Flow_Matlab_Model.m'. The script contains the following code:

```
1 - clf
2 - %load data from file first into array
3 - load Flow_Process_Reaction_Curve_a.csv;
4 - sample_time = Flow_Process_Reaction_Curve_a(:,1); %column 1
5 - flow_rate = Flow_Process_Reaction_Curve_a(:,2); %column 2
6 - plot(flow_rate);%blue line
7 - hold on;
8 - grid on;
9 -
```

The Workspace window on the right shows the following variables:

Name	Value
ans	[-21.1047;-1.8953]
Flow_Process_...	3400x2 double
flow_rate	3400x1 double
model_1	3400x1 double
model_2	3400x1 double
s	1x1 tf
sample_time	3400x1 double
system1	1x1 tf
system2	1x1 tf
t	1x3400 double

Figure 31 – MATLAB Code for Flow Control System

9.3. Caldwell Method Calculations (Flow Control System)

Using the Caldwell method, a model is created to be able to compare with the raw data from the PLC. The Caldwell method is based upon a 2nd order system being the product of two 1st order systems in series with their respective time constants τ_1 and τ_2 being two series linear lags. Caldwell's method states that 'ty' is 73% of the response final value.

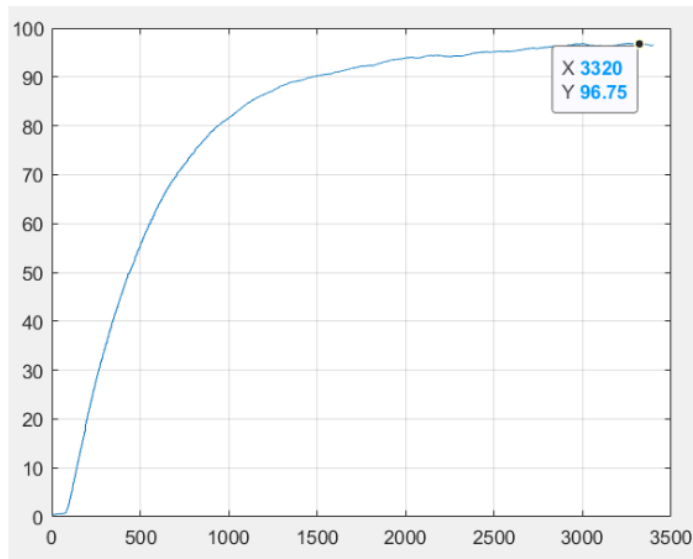


Figure 32 – Flow Process Reaction Curve

Figure 32 depicts the final value of this response at 96.75, Using Caldwell's method:

$$ty = 73\% \text{ of } 96.75 = 70.6275$$

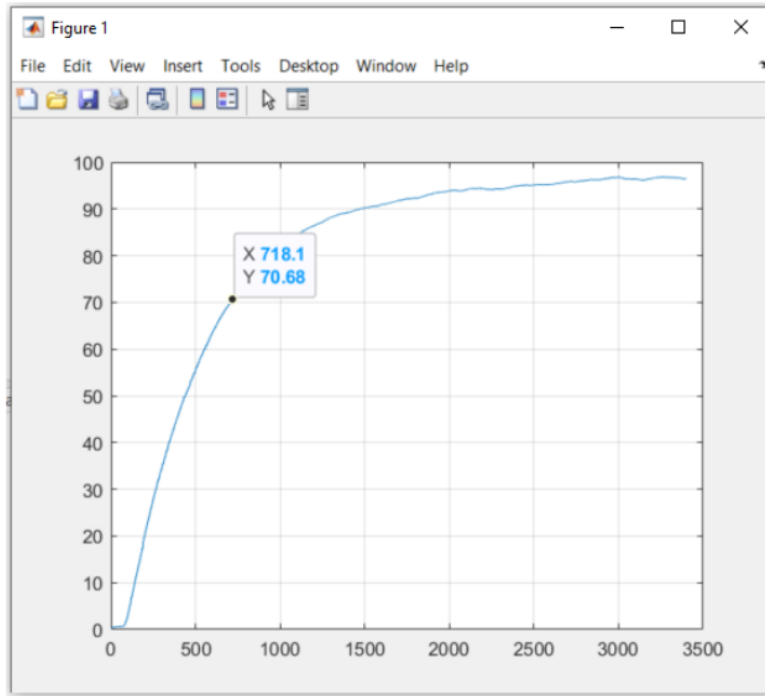


Figure 33 - Flow Process Reaction Curve ty value

Figure 33 shows that ' ty ' is found to be at 716ms or 0.716s.

Caldwell's method states that:

$$t_1 + t_2 = \frac{ty}{1.32} = \frac{0.718}{1.32} = 0.544$$

tx is found using:

$$tx = \frac{\tau_1 + \tau_2}{2} = \frac{0.544}{2} = 0.27ms$$

x is calculated:

$$x = \frac{31.05}{96.75} = 0.321$$

By following this value from the y axis on the Caldwell fractional response graph in figure 34 the value of $\frac{\tau_2}{\tau_1 + \tau_2}$ can be found as 0.835.

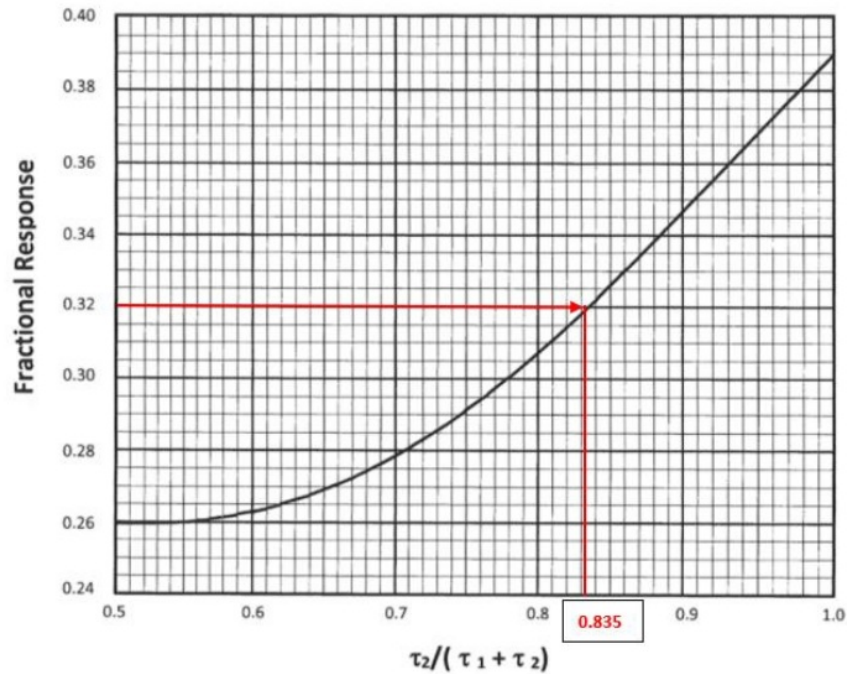


Figure 34 – Caldwell Method Graph

The values of τ_1 and τ_2 can then be found:

$$\tau_2 = 0.835 \times (\tau_1 + \tau_2)$$

$$\tau_2 = 0.835 \times 0.545 = 0.458$$

$$\tau_1 = 0.545 - 0.458 = 0.087$$

The multiplying process is used to find the transfer function for the comparison model:

$$H(S) = \frac{1}{\tau_1 \tau_2 s^2 + (\tau_1 \tau_2) s + 1}$$

Rearranged in standard form:

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

Insert values for τ_1 and τ_2 :

$$G(S) = \frac{1/0.087 \times 0.458}{s^2 + \left(\frac{0.087 + 0.458}{0.087 \times 0.458} \right) s + \frac{1}{0.087 \times 0.458}}$$

Simplified transfer function:

$$G(S) = \frac{25.09}{s^2 + 13.68s + 25.1}$$

From the calculations above, a new transfer function was inserted into MATLAB alongside the original function from the PLC. The code for this is shown in figure 35.

```
12 - s=tf('s');
13 - system1 = 25.09/(s^2 + 13.68*s + 25.1)
14 - pole(system1)
15 - model_1 = step(96.79*system1,t);
16 - plot(model_1);%red line
17 - hold on;
```

Figure 35 – Transfer Function Code

The process reaction curve for the new transfer function shown in figure 36 shows that it is a more refined response with less ripples and distortion. However, in places it runs parallel to the original response whereby in an ideal scenario it would run tight to the original response.

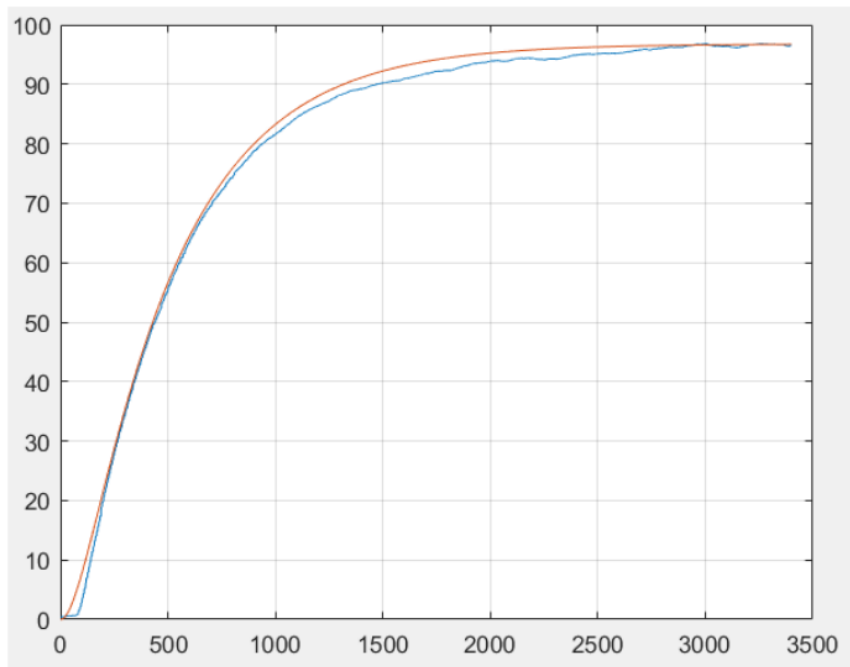


Figure 36 – Original Response vs Transfer Function Response

In order to improve this response, adjustments were made using trial and error and a new section of code was added within MATLAB in order to make comparisons (Figure 37). The values of the transfer function were tuned in order to achieve a higher performing response.

```
18 %adjust to make improvements
19 - system2= 25.8/(s^2 + 14.8*s + 25.8);
20 - pole(system2);
21 - model_2 = step(96.79*system2,t);%yellow line
22 - plot(model_2);
```

Figure 37 – Adjusted Transfer Function Code

The process reaction curve for the adjustments shows that it has tighter response to the original reaction curve whilst still keeping a more refined response with less distortion. (Figure 38

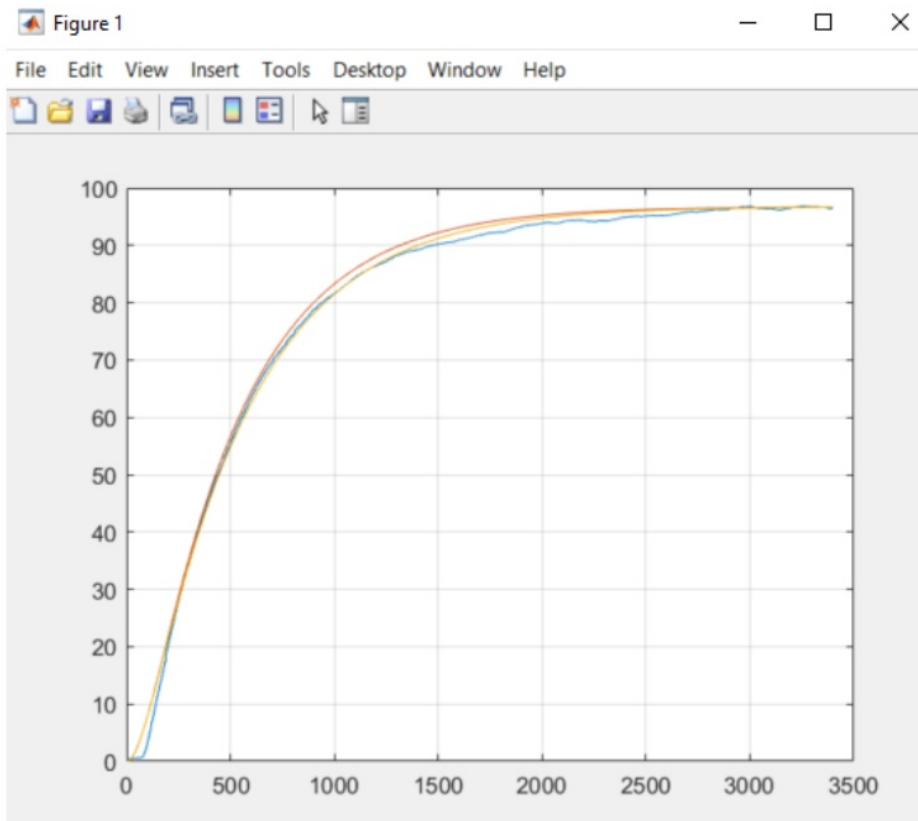


Figure 38 - Original Response vs Adjusted Transfer Function Response

9.4 Ziegler-Nichols Calculations (Flow Control System)

$$L = 0.081s \text{ or } 81ms$$

$$T = 716 - 81 = 635$$

$$R = \frac{\Delta Y}{T} = \frac{96.75}{635} = 152.4$$

$$K_P = 1.2 \frac{\Delta C}{RL} = 1.2 \left(\frac{100}{153.362 \times 0.081} \right) = 9.723$$

$$K_I = \frac{K_P}{2L} = \frac{9.723}{2 \times 0.081} = 60.019$$

$$K_D = 0.5 K_P L = 0.5(9.723) \times 0.081 = 0.394$$

9.5 Level Gradient Calculations

The transfer function was mathematically calculated as seen below:

$$\Delta X = X_2 - X_1, \text{ therefore } \Delta X = 215 - 44 = 171$$

$$\Delta Y = Y_2 - Y_1, \text{ therefore } \Delta Y = 19.526 - 1.911 = 17.615$$

$$m = \frac{\Delta Y}{\Delta X} = \frac{17.615}{171} = 0.103017$$

$$H(S) = \mathcal{L}^{-1} \int_0^{\infty} 0.103017 dt = \frac{0.103017}{s}$$

9.6 Temperature Gradient Calculations

The transfer function was mathematically calculated as seen below:

$$\Delta X = X_2 - X_1, \text{ therefore } \Delta X = 788 - 157 = 631$$

$$\Delta Y = Y_2 - Y_1, \text{ therefore } \Delta Y = 43.55 - 18.265 = 25.285$$

$$m = \frac{\Delta Y}{\Delta X} = \frac{25.285}{631} = 0.04007$$

$$H(S) = \mathcal{L}^{-1} \int_0^{\infty} 0.04007 dt = \frac{0.04007}{s}$$

9.7 – Flow Control System HMI Evidence

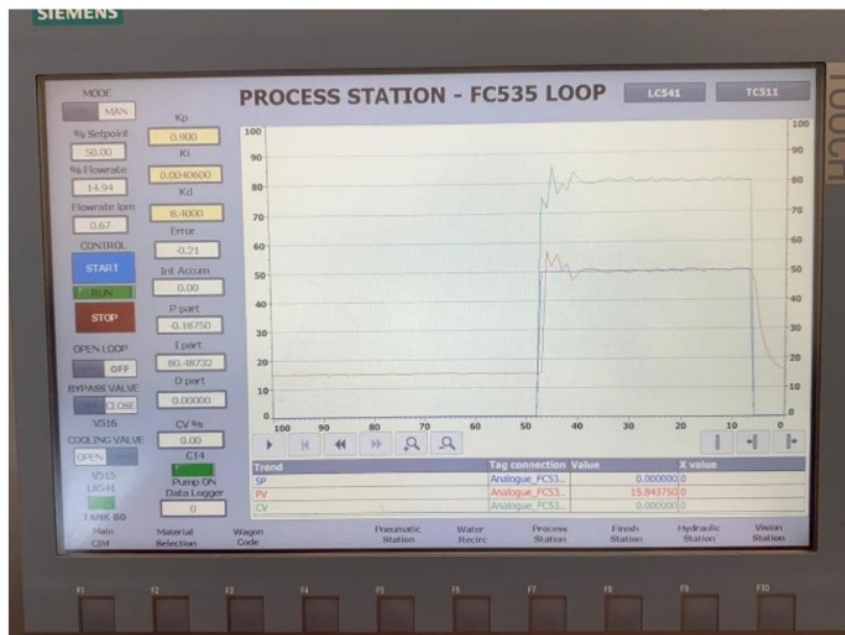


Figure 39 – Flow Control System Run with Simulink tuned values

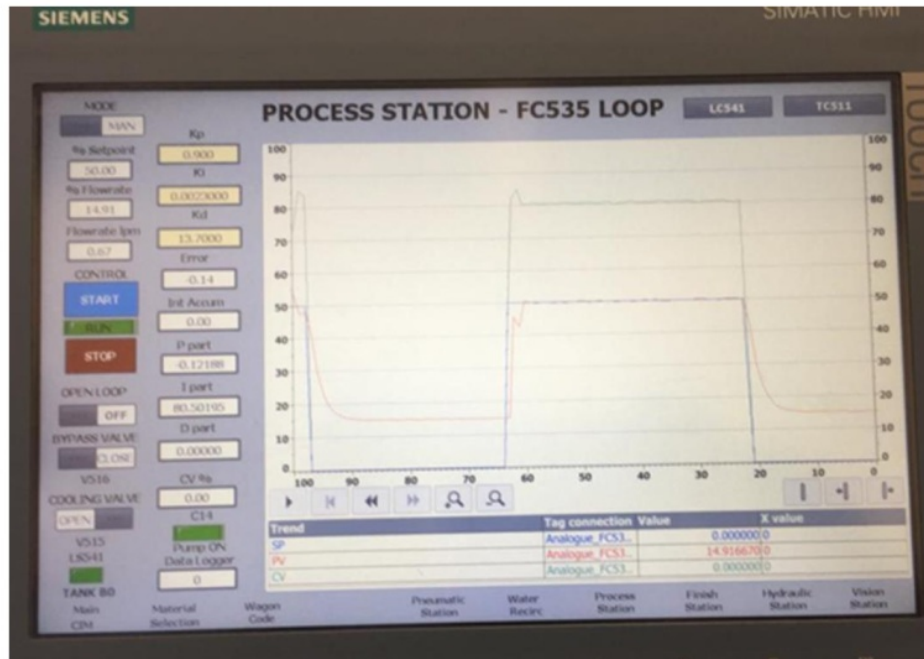


Figure 40 - Flow Control System Run with fine- tuned values

9.8 Level Control System HMI Evidence

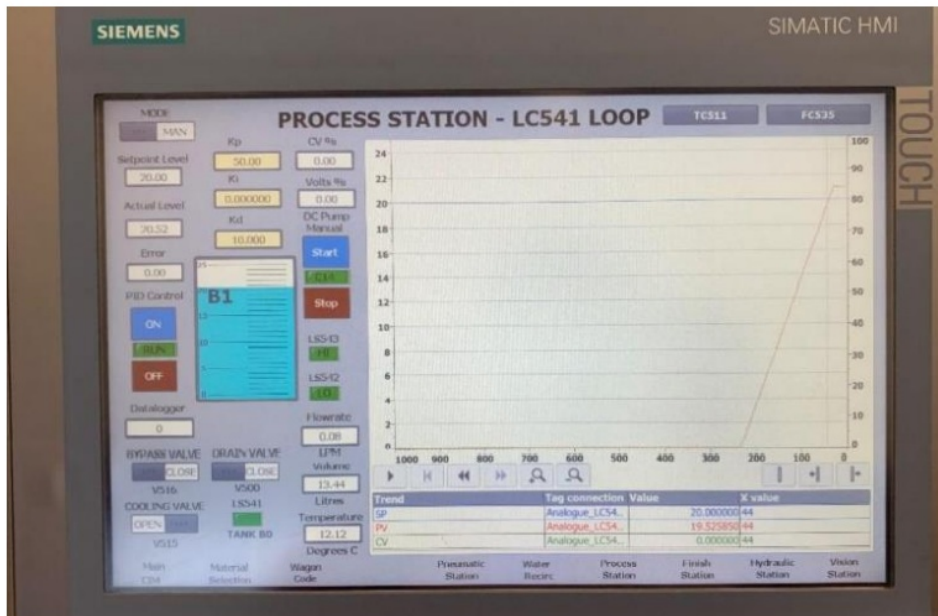


Figure 41 - Level Control System Run with Simulink tuned values

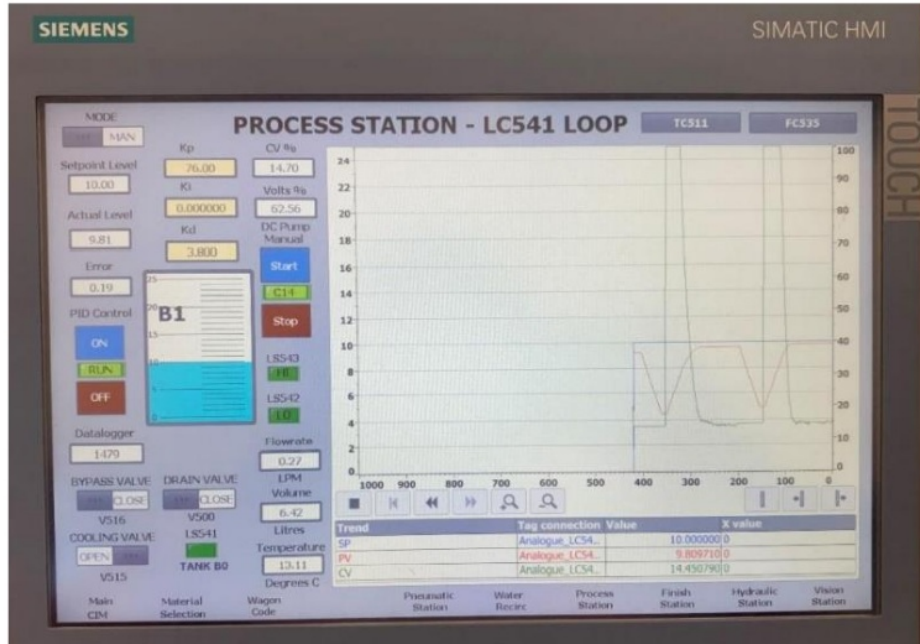


Figure 42 - Flow Control System Run with fine-tuned values

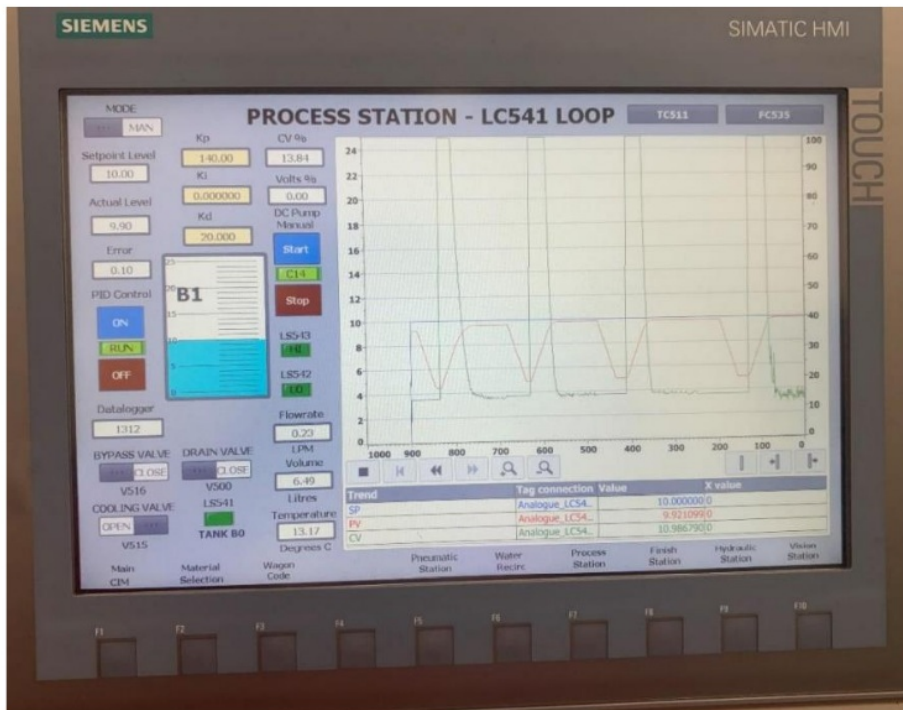


Figure 43 - Flow Control System Run with further fine-tuned values

9.9 – Temperature Control System HMI Evidence

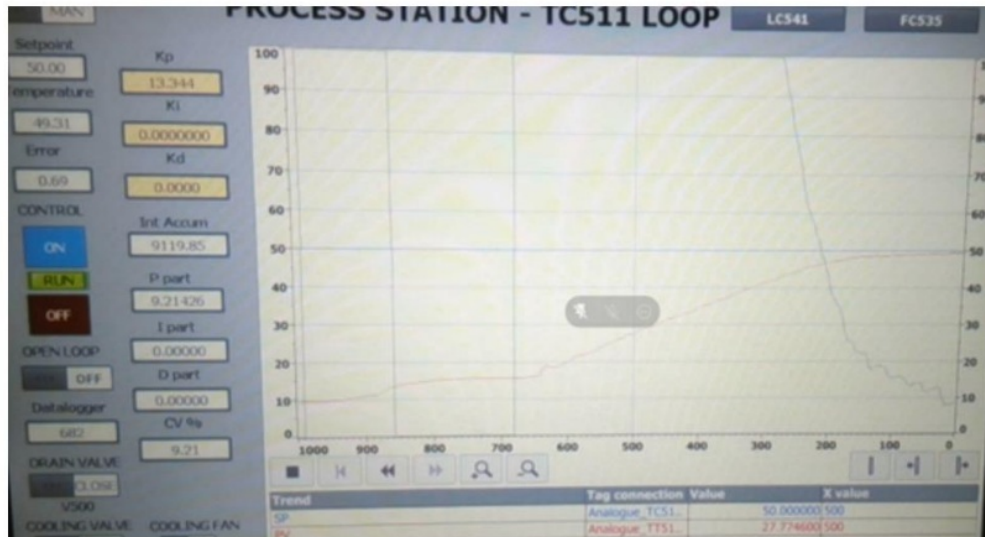


Figure 44 – Temperature Control System Run with Simulink tuned values

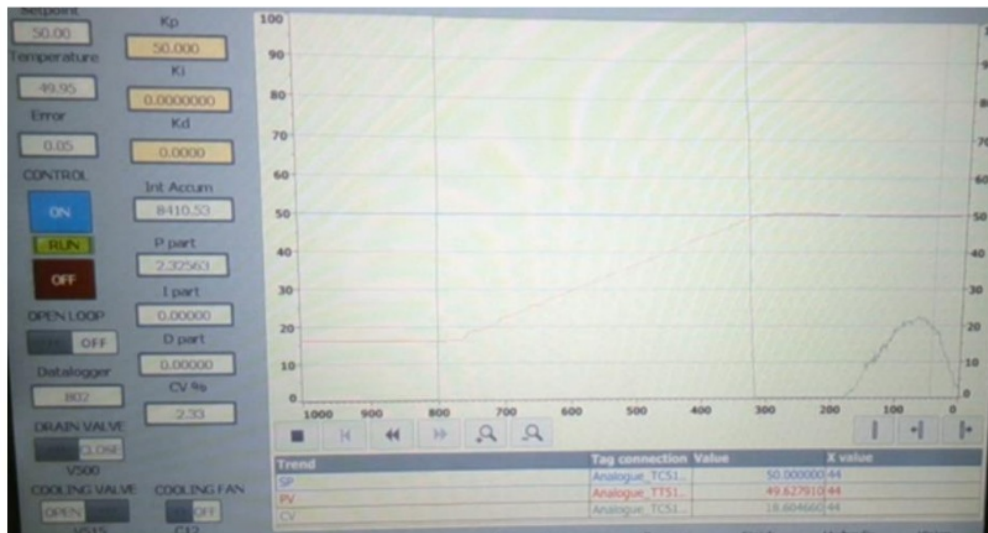


Figure 45 - Level Control System Run with final fine-tuned values

1809799

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

74/100

Instructor

PAGE 1

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

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PAGE 8

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. This this table is an image, it would be better in the appendix

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

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Citation method conforms to Harvard standard, well done.

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Correctly cited

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QM

Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. This diagram is not specific to temperature and could be for any control loop

QM

Correctly cited

Citation method conforms to Harvard standard, well done.



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Repetition

Already stated elsewhere, repeating information is considered boring by your reader

PAGE 33



Correct method of listing.

You have listed your sources correctly according to the Harvard method.



Wide Range of Sources

You have shown good evidence of reading from a wide range of sources.

GRADING FORM: NEW CSG-RUBRIC

1. ENGAGEMENT WITH LITERATURE



Exceptional engagement with an extensive range of relevant and credible literature. High-level referencing skills consistently applied. (18/20)

18

2. KNOWLEDGE AND UNDERSTANDING



Excellent, detailed knowledge and highly critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. (14/20)

14

3. COGNITIVE AND INTELLECTUAL



Excellent critical evaluation and analysis of concepts and principles leading to logical, evidence-based, reasoned arguments and judgements. Explicit recognition of other stances and a strong awareness of the limits of their knowledge. A capacity for independent thought and ability to 'see beyond the question', suggesting some grasp of the broader field and wider concepts. (16/20)

16

4. PRACTICAL APPLICATION



An advanced application of a range of established methods, materials, tools and/or techniques. The context of the application is well considered, and insightful. Consistent, accurate and logical application of theory to practice, making well-developed links between the two. Can identify problems and propose excellent, creative solutions outside the context in which they were first studied. (16/20)

16

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. (15/20) Word count exceeded 5 marks deducted.

10