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by Matthew Perry

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1. Executive Summary *A good but not complete summary*

Within this assignment, research on PID tuning methods has been carried out. By researching the different methods, the most suitable approach for the student was decided. By implementing the model-based method for a level control and temperature application, measurements were completed to then predict values such as time constant and gain to then compare them against the simulated model. Using the simulated model, the PID controller was fine-tuned using manual adjustments for the values of K_i , K_p and K_d . Disturbances were then applied to analyse how well the system reacted. A conclusion was drawn on how well the systems managed and overall findings.

Paragraphs should be fully justified text as required in the brief

What was your conclusion?

2. Work plan for Life-long Learning

This assignment will be completed methodically by researching different approaches to tune PID loop parameters. From this research, A preferred method will be then implemented into creating level control of a process tank and temperature control of a heater tank. Results will be recorded from both tasks and analysed in the conclusion.

From this assignment, the student has gained a in depth understanding of different methods of designing PID parameters. It was decided that the most suitable method, was the model-based method. By implementing this method, it could be shown how a system would operate, how it would react with different parameters and how to decide the optimal parameters for the system. By comparing the calculated, measured and simulated values it shows that the method was accurate. Lastly, the teamworking sections in this assignment allowed the student to enhance their communication skills.

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3. Research

3.1 Method 1; Trial and Error

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Trial and error tuning can be used to tune the parameters of PID controller by analysing the dynamic behaviour of the controlled process output (Woolf, 2022). There are 5 behaviours of how a process output can react dependent on the tuning parameters for the step setpoint change. The 5 behaviours can be described as

Correctly cited

- Behaviour 1 – If the process displays a big oscillation, then the proportional gain is too large.
- Behaviour 2 – if the controlled process output displays an overdamped response, then the proportional gain is too small.
- Behaviour 3 – If the process output oscillates and remains above the setpoint longer than under the setpoint then the integral time is too small.
- Behaviour 4 – If the process output oscillates and the output stays under the setpoint longer than above the setpoint then the integral time is too large.
- Behaviour 5 – If the process oscillates at a high frequency from the start of the process to the steady state, then the derivative is too large.

By understanding these behaviours, it is then possible to try reducing the above-mentioned dynamic behaviours by adjusting the tuning parameters. Lastly, it is important to note for successful trial and error tuning to sustain the proportional gain as large as possible (Su Whan Sung, 2009).

Correctly cited

3.2 Method 2; Kappa Tau

Kappa-Tau requires limited plant knowledge that can then be characterised as

$$\tau = \frac{L}{L + T}$$

This parameter is called the normalised dead-time and can be thought of as the classical controllability ratio. To be able to then design the tuned process, test batches must be carried out on the plant and then an appropriate transfer function must be selected that is indicative of the process, in most cases this would be

$$G(s) = Kp \frac{e^{-Ls}}{(1 + sT)}$$

A load disturbance is applied to the process input and then an error can be analysed and reduced through a mathematical model. The maximum sensitivity value can be found on a Nyquist curve which is used as a tuning parameter (Mathworks, 2021). This value can then be used for a standard measure of the robustness, which then leads to the corresponding tuning rules.

Essentially, this design method revolves around reducing the integral error. This improves disturbance rejection which is limited by the maximum sensitivity function (Ms). Tuning values are determined by the four robustness levels proposed which only rely on the normalised time delay (Gude, 2012).

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3.3 Method 3; Cohen-Coon

The Cohen-coon tuning design uses three process characteristics: process gain, time constant and dead time. These characteristics are determined by carrying out step tests and analysing the results.

A process should be carried out until the settling time, then a step change of a couple of percent in the controller should be altered and wait for the process variable to stabilise to the new value. The total change obtained in the PV should be calculated to a percentage of the span of the measuring device. Then the process gain can be calculated by

$$pG = \frac{\text{Change in PV \%}}{\text{Change in Controller \%}}$$

The inflection point can be found from the PV response curve and a line should be drawn tangential to the PV response curve through the point of inflection and extended down to intersect with the original level of the PV and then note the time value. The dead time which is the time difference between the change of the controller and the intersection of the original PV level can be measured. Then calculate the process value at 63% of its total change and measure Tau. New tuning values can be calculated from the tuning equations shown in Table 2. Lastly, the controller gain should be divided by 2 to reduce oscillations and improve loop stability (Smuts, 2011). Correctly cited

3.4 Method 4; Lambda

The lambda tuning method has three steps, these are

1. Identify the process dynamics.
2. Choose the desired closed loop speed response (lambda).
3. Calculate the required PID tuning constants.

The process dynamics can be gathered from an open loop output step tests which can determine the dynamic parameters such as deadtime and integrating process gain.

Lambda can be used to achieve the desired process control requirements. Beall states Correctly cited "Without using derivative, the minimum lambda considering stability and resonance requirements is approximately $3 \times (\text{dead time plus lag time constant})$. Using derivative, the minimum lambda considering stability and resonance requirements is approximately the larger of the dead time or the lag time constant." (2016, p. 1)

Finally, the PID tuning constants can be calculated by the following equations.

$$\text{Integral time} = \text{Primary time constant}$$

$$\text{Controller Gain} = \frac{\text{Integral time constant}}{KP (\lambda + T_d)^2}$$

$$\text{Derivative time} = \text{Secondary time constant}$$

3.5 Method 5; Model Based

In the model design, designs are limited to two types: first and second order. If a second order is desired, then approximation is often involved to obtain a model. For a first order model, it can be assumed that the time and a steady state gain (K) form the Laplace transfer function. Inserting the transfer function into a computing software such as Simulink, the P, PI and PID values can be determined (IPCOS, 2021). Correctly cited

In summary, model-based method requires process data which can be successfully gathered from 'bump test' which is accurate of the actual process behaviour. This means to make a setpoint change and record the controller output and process variable data. Then fit a first order plus dead-time dynamic model to the process data. (Base, 2021). Correctly cited

3.6 Comparison of Methods

All methods have been compared with each other regarding pro's, cons and suitability in Table 3

By investigating different approaches to PID tuning methods it can be shown that they have different reactions and are suited more towards specific systems. The chosen method to implement will be the model-based method. This is because a suitable plant model can be built, and simulations can be carried out offline. A specific process reaction curve can be selected by varying the parameters on Simulink which would allow the system to be very accurate.

A good research section and conclusion

4 Level Control of the Process Tank

4.1 CE117 Level Investigation

The CE117 Process trainer is a benchtop process control apparatus that can control parameters such as flow, level, temperature, and pressure. In this task, level is being focused on. Below shows a P&ID diagram that can regulate the level in the process tank.

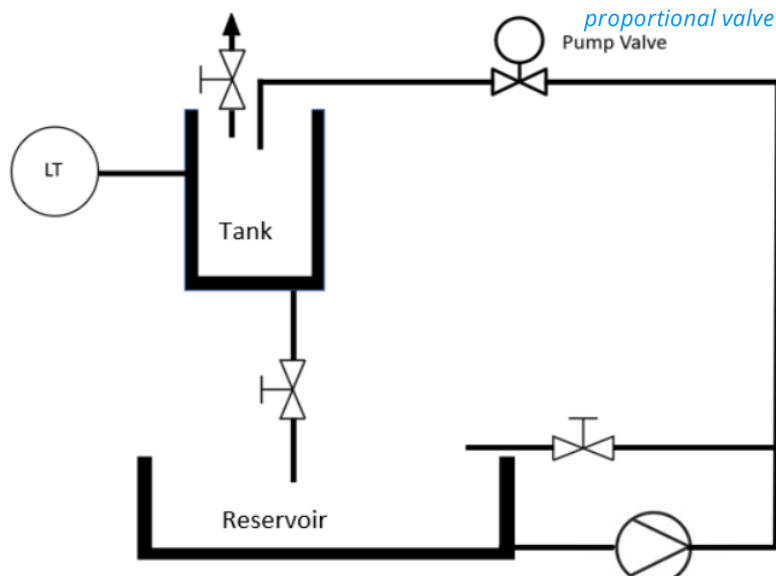
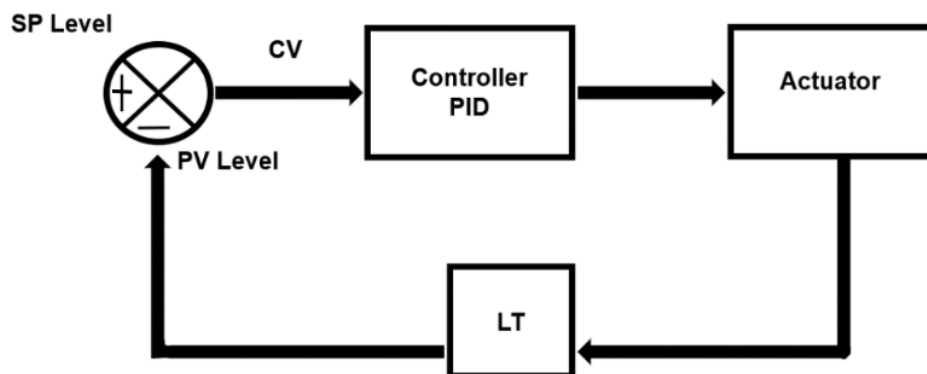


Figure 1; P&ID Level Control

The process tank is a transparent cylinder with a scale in (mm) vertically to accurately read the level by sight. The reservoir is filled with water and pump 2 will drive the water upwards into the process tank via the proportional valve (pump valve) and cooler. The water then returns to the reservoir via the manual valve at the base the process tank. Additionally, the process tank has a capacitive level transmitter (LT) which is mounted vertically. This operates by a parallel plate capacitor made up of two concentric cylinders which are electrically insulated from each other and with air occupying the space between the cylinders (TecQuipment Ltd, 2008). A visual aid of the diagram can also be shown in Figure 5 and a table displaying the instruments and actuators operating parameters in Table 6.

Paragraphs should be fully justified text as required in the brief

Below shows the control block diagram, it can be shown that the controller varies the actuator (pump 2) which is read by LT (capacitive level transmitter) and is fed back into the accumulator. A CV is then fed back into the controller and continues.



Control Block Diagram

does this label need to be so large?

Figure 2; Control Block Diagram Level

4.2 Calibration Curve

A calibration curve was obtained by using manual controls. The range of depth of the vessel to be filled was determined which was agreed on 0mm to 180mm. Using the potentiometer on the control board, the pump was manually controlled to turn on and off at the desired intervals (10mm) while taking readings of the level transmitters output voltage. Inserting the data collected into an Excel spread sheet, a graph was created shown in Figure 6.

From the graph is shows an almost linear pattern between the level of the tank and level transmitter voltage. It shows that the level transmitters voltage ranges from 0-10V and at 0mm level (empty) the voltage is 0.03V and at 180mm level (full) it is 10.015V. This shows that the transmitter is fairly accurate with small discrepancy.

4.3 Calculating Time Constant

To calculate the time constant, some data about the system needed to be recorded. The water level would be increased starting from just above the heat exchanger coil. This is because, the coil takes up area within the tank which would cause a non-linear time constant for that period. From to the two points, (A & B), voltage values were recorded for the pump, flow and level also including the flowrate (m³/ sec) and level (m) compiled in Table 4.

Using the results gathered, suitable calculations were made to determine the time constant of the process shown in Figure 7. Ultimately, the change in level and flow rate between the two points divided by each other and then multiplied by the area of the vessel results in the time constant. Shown as

$$\Delta H = 01.149 - 0.118 = 0.031$$

$$\Delta Q = 73.5 \times 10^{-6} - 69.33 \times 10^{-6} = 4.17 \times 10^{-6}$$

$$R = \frac{\Delta H}{\Delta Q} = \frac{0.031}{4.17 \times 10^{-6}} = 7434.053$$

$$A \times R = 0.01767 \times 7434.053 = 131.361 \text{ Seconds}$$

The gain of the system can be calculated as the difference in voltage for level sensor divided by the difference in the pump voltage. Shown as

$$K = \frac{\Delta V_L}{\Delta V_P} = \frac{1.385}{0.5} = 2.77$$

$$\frac{2.77}{131.36 \text{ s} + 1}$$

4.4 Experiment to Measure Time Constant & Gain

In the experiment, the process trainer was connected to the PC to control the voltage for pump 2. Originally, the pumps output was set to 5.3V while resting at a level of 120mm where flow in matched flow out, then implementing a step change of 0.5V increased the voltage output to 5.8V where the level rested at 150mm. While this was being carried out, the CE2000 program logged the data to then produce a graph shown in Figure 8. Using the tools equipped within the software and selecting a linear region of the graph the time constant was shown to be 131.15 seconds.

Referencing Table 5, it shows that there was a 211-millisecond discrepancy between the measured and calculated value.

4.5 Simulated Model

Using a mathematical model based on the results calculated, a simulation was created on Simu-Link. The model can be shown in Figure 10. This model is made up of several blocks, the first is a step block that provides a step between two definable levels (0-12), and then moves into a summing block which moves the added value into a PID Controller. Within this block there are general initial parameters set for K_i , K_d and K_p with an additional auto tune function. Following the PID block there is a saturation block that produces an output between the upper and lower limits (0-10). Then the model of the system in terms of the transfer function is in next, with a graph recorder. The feedback is then fed into the summing block to be subtracted from the next input.

By running the simulation, the software produces a linear plant model from the Simulink model and an initial controller. The PID controller can be further tuned with the manual controls which can select whether the system should respond faster or slower but also how the transient behaviour should react whether its aggressive or robust. By selecting the characteristics, the software then varies the parameters of K_i , K_d and K_p .

What were your values of K_p , K_i and K_d ?

Initially the performance of the simulation is adequate however, it was optimised for the best performance using the manual adjustments. The performance of the simulation can be shown in Figure 11. The tuned column shows the standard tuning provided by the software, whereas the block response is the manually adjusted controls. This shown that the adjusted control resulted in a faster rise and settling time while sacrificing a 2.84% increase in overshoot.

Paragraphs should be fully justified text as required in the brief

4.5 Implementing Control Method

Implementing the K_p , K_i and K_d values created from the simulation into the CE117 process trainer software a setpoint was then then decided on 140mm. Initially the level was set to 130mm with the drain valve partially open, the pump voltage was increased by 0.5V. The level increased and overshoot the setpoint but then settled.

The first disturbance, the drain valve was closed slightly which initially increased the level and the pump voltage decreased. While the pump voltage decreased, the flow in versus flow out settled at 140mm.

Secondly, the drain valve was opened further which increased the flow out, thereby decreasing the level. The pump voltage increased and recovered the level with little overshoot.

Lastly, the drain valve was opened, and the level decreased while the pump voltage increased. Before the setpoint was reached, the drain valve was then closed slightly. This led to the system overshooting the setpoint however it did settle.

A graph which was recorded using the CE117 process trainer that can be viewed in Figure 12.

In summary, the system handled the disturbances well. Although there was overshoot while trying to reach the setpoints the rise time and settling time responded excellent.

5 Temperature Control of the Heater Tank

5.1CE117 Temperature Investigation

There are instrumentation and control actuators that are used to control the temperature in the tank. Below shows a P&ID diagram that includes these instruments and actuators and the operation of the system.

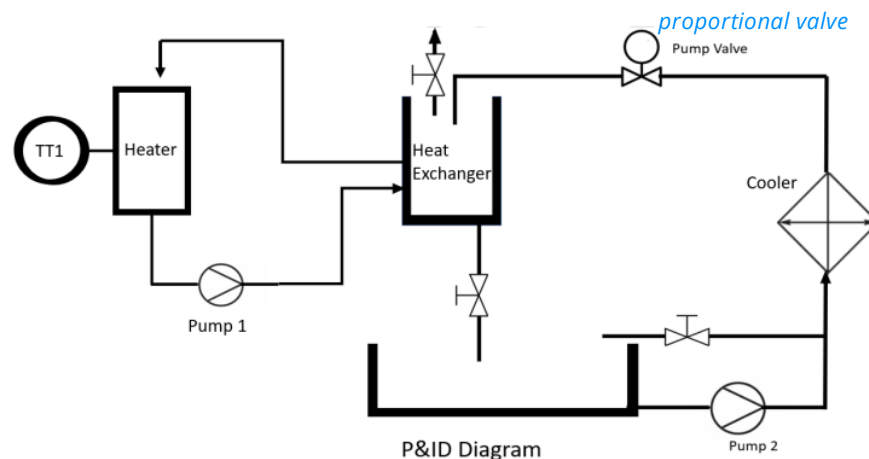


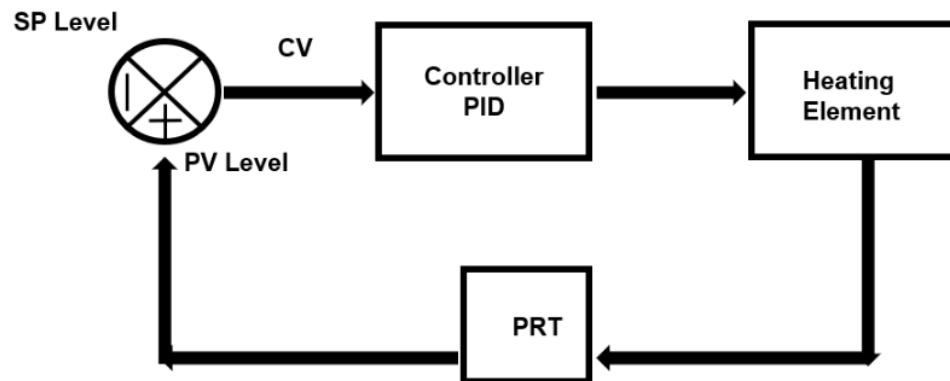
Figure 3; P&ID Temperature

The heater loop consists of a heater tank and a loop exchanger which passes through the process vessel. The heater tank contains an electric heater element and a temperature sensor. The temperature sensor used is a platinum resistor thermometer. This sensor is made up of a platinum wire that determines the temperature by measuring the electrical resistance (NPL, 2022). [Correctly cited](#)

The water is pumped through the heat exchanger by the control of pump 1. The heat exchanger works by using convection. The heat is transferred from the hot inner fluid produced by the heating tank to the tube wall via convection, it then conducts through the pipe wall to the other side and the outer fluid carries this away also through convection (Hard, 2021). [Correctly cited](#)

The instruments on the right side of the diagram have been used to create disturbances to see how the systems reacts. Pump 2 delivers the water from the reservoir into the process tank via a cooler and proportional valve. A table has been created that displays all operating voltages for the instruments and actuators, shown in Table 7.

Below shows the control block diagram, it can be shown that the controller varies the heating element which is read by the PRT (Platinum resistance thermometer) and is fed back into the summing point for comparison with the input. The CV is then fed back into the controller and continues.



Control Block Diagram

Figure 4; Control Block Diagram Temperature

It is worth noting, that when disturbances are applied it is after the heating element and before the PRT sensor which can also be referenced in Figure 5.

5.2 Time Constant & Gain

The process tank was filled using the level controller running at a suitable setpoint above 140mm to ensure the heat exchanger was covered. Additionally, the level within the heater tank was adequate to prevent the interlock from cutting the operation out. The proportional valve was half open with pumps 1 & 2 set to 5V to create a set level. Then the heater was set to 3V while the PRT read 27.3V. Implementing a step change of 3V to the heater, this resulted in the temperature sensor increasing to 3.185V.

By using the results from the experiment, the gain of the system can be calculated as

$$K = \frac{\Delta VT}{\Delta VH} = \frac{0.455}{3} = 0.1516$$

To calculate the time constant, a setpoint was set on the CE117 process trainer and then a step voltage was applied to the heater. The temperature rose and using the software's tools the time constant was measured at 579 seconds. The system can then be shown as a transfer function. The transfer function of a system is a mathematical model in that it is an operational method of expressing the differential equation that relates the output variable to the input variable (Pearson Higher Education, 2009). Shown as:

$$\frac{0.1516}{579s + 1}$$

5.3 Temperature Simulation

Using the MathWorks's Simu-link software a mathematical model of the system was created. A diagram of this model can be shown in Figure 17, this model follows the same structure described in Figure 10 however the transfer function is different due to the gain and time constant. The gain is larger which means the process variable moves more to a change in the output controller (Control Station, 2018). Correctly cited

Using the system created, the PID controller was used to auto tune the system. Referencing Figure 16 the tuning that the software provided labelled 'tuned' was adequate however it had a slow transient time, overshoot and some undershoot. Using the manual adjustments, the tuning could be improved so that the response time and settling time could be reduced while decreasing overshoot and removing undershoot. This was done by having a larger proportional and integral gain.

What were your values of K_p , K_i and K_d ?

5.3 Implementing Temperature Control Method

Collectively, it was agreed that the derivative gain was not necessarily due to the inclusion of the heat exchanger which dynamics are sufficiently fast (Control Station , 2015). Correctly cited
Implementing the optimised tuned values using the CE117 software the disturbances were introduced to analyse how the process reacted.

The heater was set at 3V while the PTR read 3V (30 degrees). Creating a new setpoint to 3.2 (32 degrees) the temperature rose and overshoot the setpoint. During this initial climb of temperature, it can be shown that the heater CV increased to its maximum value and then reduced after it overshoot.

The first disturbance included increasing the pump 2 voltage and the fan speed within the cooler. This will increase the input of cooler water effecting the heat exchanger. By analysing the graph, it shows that the heater CV increased while slowly decreasing. The PV was barely affected by this disturbance.

The second disturbance introduced was increasing the pump speed of pump 1 by increasing the input voltage from 5V to 7V. This disturbance did not show on the temperature sensor, and the heater CV spiked very briefly.

The third disturbance pump 1 & 2 the voltages were halved, this meaning the circulation of the waterflow would be reduced in an attempt for the water temperature to exceed the setpoint. This resulted in the temperature exceeding while the cv increased and decreased to stabilise the PV.

In conclusion, the control method worked very well, the system reacted quickly and aggressively against the disturbances to ensure there was little error when the disturbances were applied. At times after the disturbance, it can be shown that there is a small steady state error.

6 Conclusions and Recommendations

In conclusion, this assignment has researched into multiple ways of designing a PID control. From the investigation it was determined that the model-based method would be the most suitable. The selected method was implemented into two first order systems which were level and temperature.

In the temperature task, a suitable experiment to calculate the time constant & gain was carried out, then by using these values they were then put into a mathematical model to simulate. The values that were calculated compared well with the measured value with a discrepancy of 211 millisecond regarding the time constant. Once the simulated model was created, an auto tune feature was used to determine the best parameters for the PID. Although these resulted in an adequate response, the control loop could be optimised using manual adjustments within the software to reduce the rise time, settling time while sacrificing a small amount of overshoot.

During the temperature task, the same method was applied to acquire the time constant value and gain. It was shown that using implementing the calculations into a simulated model the system could be tuned but also optimised via manual adjustments. Using the manual adjustments, it improves the performance dramatically. The rise time decreased by 412 seconds, the settling time more than 10 minutes and the overshoot by 4%. It was decided that derivative gain would not be used within the controller. Due to its application additional derivative term does not provide significant benefit over a PI controller and results in an increase in complexity (MapleSoft, 2013). After a disturbance was applied, there was a small steady state error, in hindsight this could have been removed or reduced by increasing the value of K_i . This is because the response the response creeps slowly towards the setpoint for small values of k_i . The approach is faster for larger integral gains; however, the system can become more oscillatory (Honeywell, 2000).

Lastly, this assignment has allowed the learner to gain knowledge on how to design and apply the model-based method to other applications. In future designs, it would be beneficial to record the pump voltage when measuring setpoint and level. This would show how the pump reacts to the disturbances. The graphs used within the equipment software could have better labelled axis for smaller increment measurements. Additionally, the student would like to investigate how calculate the time constant for a thermal exchange when a step input is applied.

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Good conclusions and recommendations

7 Team Working

Within this assignment, groups were assigned to carry out the experiments. This was beneficial to the student because to become a successful engineer is to develop strong teamwork skills to ensure a smooth workflow process (ESILV, 2019). Correctly cited

Before starting the tasks, within the group a discussion was held to talk about if anyone had any needs, and how they could be met. By doing so, everyone involved in the group felt included and safe.

Reading the assignment brief, common goals were set to obtain the data required and as a group, our roles were assigned. During the level task Matthew used the potentiometer to control the speed of the pump and to stop it correct level when informed by Harri. Aeron then used the software to take the readings from the software and input them into an excel spreadsheet. Once this was complete, a discussion was held about the findings, from this it showed that the level transmitter was almost linear. Lastly, for this task as a group each member took turns to create the disturbances.

Lastly, during the temperature task similar roles were assigned, however Matthew used the PC to control the heater by increasing and decreasing voltage to supply for the instruments while Harri and Aeron recorded the results.

Paragraphs should be fully justified text as required in the brief

8. Works Cited

Base, B., 2021. *Model-based Tuning Methods for Pid Controllers*. [Online]

Available at:

https://www.streetdirectory.com/travel_guide/119107/science/model_based_tuning_methods_for_pid_controllers.html

[Accessed 10th November 2022].

Beall, J., 2016. *Loop tuning basics: Complex process responses*. [Online]

Available at: <https://www.isa.org/intech-home/2016/september-october/features/loop-tuning-basics-complex-process-responses>

[Accessed 5th November 2022].

Control Station , 2015. *Common Industrial Applications of PI Control*. [Online]

Available at: <https://controlstation.com/blog/pi-control/>

[Accessed 28th January 2023].

Control Station, 2018. *What is process gain?*. [Online]

Available at: <https://controlstation.com/blog/what-is-process-gain-why-is-process-gain-important-when-tuning-processes/>

[Accessed 27th January 2023].

ESILV, 2019. *Engineering Teamwork 101*. [Online]

Available at: <https://www.esilv.fr/en/engineering-and-teamwork-3-fundamental-skills/>

[Accessed 5th February 2023].

Gude, J. J., 2012. Kappa-tau type PI tuning rules for specified robust levels. *IFAC Proceedings Volumes*, 45(3), pp. 589-594.

Hard, M., 2021. *What is Coil Heat Exchanger? Design Example*. [Online]

Available at: <https://www.linguip.com/blog/coil-heat-exchanger-essentials-you-need-know/>

[Accessed 27th January 2023].

Honeywell, D., 2000. *Caltech*. [Online]

[Accessed 3rd February 2023].

IPCOS, 2021. *The Guide to PID tuning* , Bosscheweg: IPCOS.

MapleSoft, 2013. *PID Control*. [Online]

Available at:

https://www.maplesoft.com/content/EngineeringFundamentals/12/MapleDocument_12/PID%20Control.pdf

[Accessed 2nd February 2023].

- Mathworks, 2021. *Two-Degree-of-Freedom PID Controllers*. [Online]
Available at: <https://uk.mathworks.com/help/control/ug/two-degree-of-freedom-2-dof-pid-controllers.html>
[Accessed 3rd November 2022].
- Michigan Technological University, 2012. *Standard PID Tuning Methods*, Michigan: Michigan Technological University.
- NPL, 2022. *What is a PRT?*. [Online]
Available at: <https://www.npl.co.uk/resources/q-a/platinum-resistance-thermometer>
[Accessed 27th January 2023].
- Pearson Higher Education, 2009. Mathematical Modeling of Control Systems. In: *Mathematical Modeling of Control Systems*. s.l.:Pearson, pp. 1-4.
- Smuts, J. F., 2011. *Process Control for Practitioners*. 1st ed. Texas: OptiControls IncOptiControls Inc.
- Su Whan Sung, . J. L. I.-B. L., 2009. *Process Identification and PID Control*. 1st ed. Singapore: John Wiley & Sons, Incorporated.
- TecQuipment Ltd, 2008. *CE117 Process Trainer User Guide*. s.l.:TecQuipment .
- Woolf, P., 2022. *Chemical Process Dynamics and Controls*, California: LibreTexts.

9. Appendix

	K_c	τ_{Int}	τ_{Der}
P	$\frac{1}{rK} \left(1 + \frac{r}{3}\right)$		
PI	$\frac{1}{rK} \left(0.9 + \frac{r}{12}\right)$	$\tau_{del} \frac{30 + 3r}{9 + 20r}$	
PID	$\frac{1}{rK} \left(\frac{4}{3} + \frac{r}{4}\right)$	$\tau_{del} \frac{32 + 6r}{13 + 8r}$	$\tau_{del} \frac{4}{11 + 2r}$

Table 2; Cohen-Coon Tuning Rules (Michigan Technological University, 2012)

Water Level inside the Process Vessel (mm)	Level Transmitter Output (V)
0	0.03
10	0.6
20	1.39
30	2.285
40	3.23
50	4.025
60	4.61
70	4.965
80	5.51
90	6.085
100	6.62
110	7.095
120	7.54
130	7.975
140	8.54
150	8.89
160	9.285
170	9.655
180	10.015

Table 1; Calibration Curve - Level Transmitter

Comparison of PID Tuning Methods

Method	Most Suited	Pro	Con
Trial & Error	For plants that aren't critical due to oscillations.	Little knowledge required.	A stable response isn't guaranteed.
Kappa Tau	Plants that need to reject load disturbances.	Results in optimal disturbance rejection with no overshoot	Control objectives or closed loop performance requirements can't be defined due to 0% overshoot.
Cohen-Coon	Systems that have a time delay.	Avoids errors in estimating a and L by using the gain.	You can only use the method offline.
Lambda	Systems with a large time delay.	Enables choosing a desired closed-loop time constant	Only suited for PI controller tuning. The parameter derivative (K_d) cannot be taken into consideration.
Model Based	It's a flexible method which can search for the optimal solutions for the required system.	Allows a structured tuning process that considers both process behavior and control needs.	A strict workflow model needs to be followed otherwise the process model won't be accurate which then affects the computed parameters.

Table 3; Comparison of PID tuning methods (IPCOS, 2021)

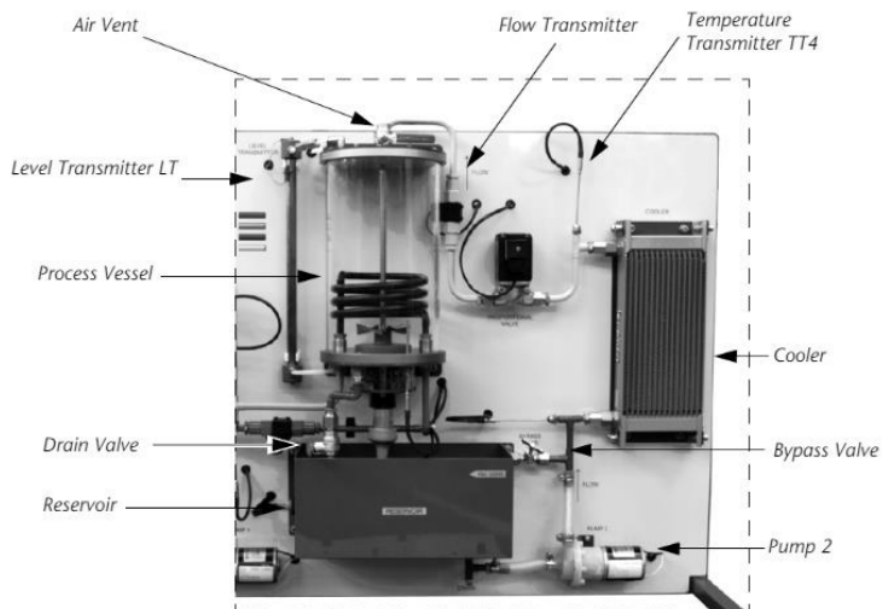


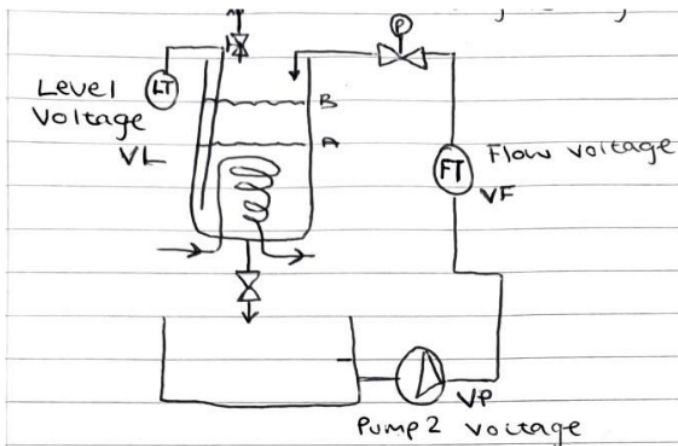
Figure 5; Process Level Visual Diagram (TecQuipment Ltd, 2008)



Figure 6; Calibration Curve Level Transmitter

Level Transmitter Time Constant Results for Calculations					
Level	VP	VL	VF	h Level (m)	q Flow Rate m ³ /Sec
A	5.3	7.752	4.16	0.118	69.33 x 10 ⁻⁶
B	5.8	8.91	4.41	0.149	73.5 x 10 ⁻⁶

Table 4; Results for Time Constant Calculations



Vessel radius

$$= 7.5 \text{ cm} = 0.075 \text{ m}$$

Area of vessel

$$= \pi r^2 = 0.01767 \text{ m}^2$$

$$1 \text{ Litre/min} = \frac{0.001}{60} \text{ m}^3/\text{sec}$$

	V_p	V_L	V_F	h level (m)	q flow rate m^3/s
A	5.3v	7.525v	4.16v	0.118	69.33×10^{-6}
B	5.8v	8.91v	4.41v	0.149	73.5×10^{-6}

$$\Delta h = 0.149 - 0.115 = 0.031$$

$$\Delta q = 73.5 \times 10^{-6} - 69.33 \times 10^{-6} = 4.17 \times 10^{-6}$$

$$R = \frac{\Delta h}{\Delta q} = \frac{0.031}{4.17 \times 10^{-6}} = 7434.1$$

Time Constant $\tau = \text{Area} \times R$

$$= 0.01767 \times 7434.1 = 131.361 \text{ sec.}$$

Figure 7; Calculating Time Constant Level Transmitter

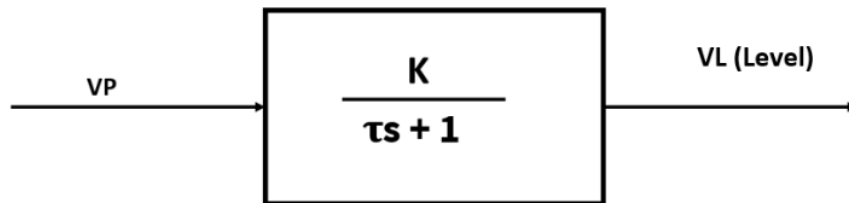


Figure 8; Level Response Gain

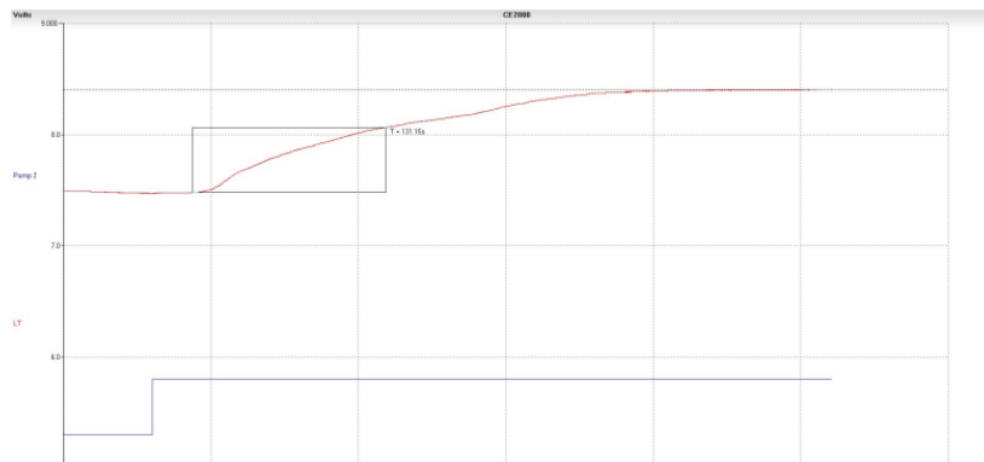


Figure 9; Level CE2000 Graph

<u>Comparison of Calculated Versus Measured (Level)</u>			
	Calculated	Measured	Error
Time Constant	131.361	131.15	0.211

Table 5; Comparison of Tau, Calculated Versus Measured

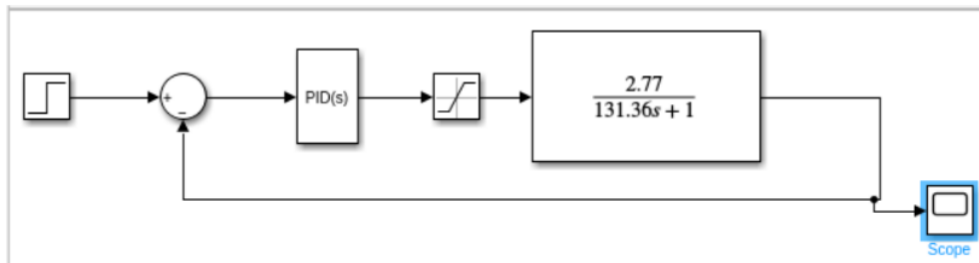


Figure 10; Simulated Model Level

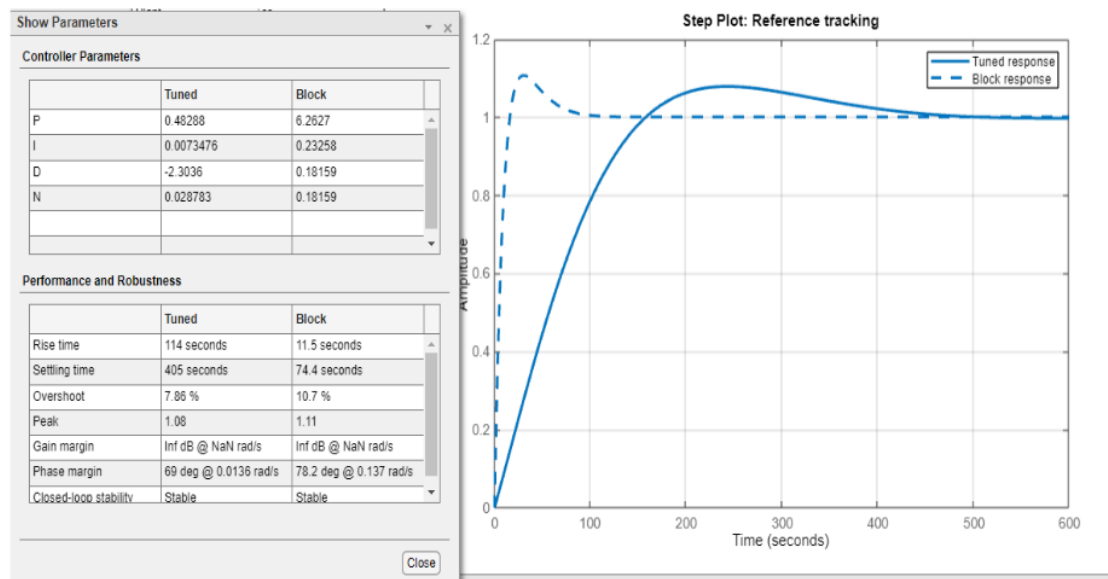


Figure 11; Level PID Tuned Values

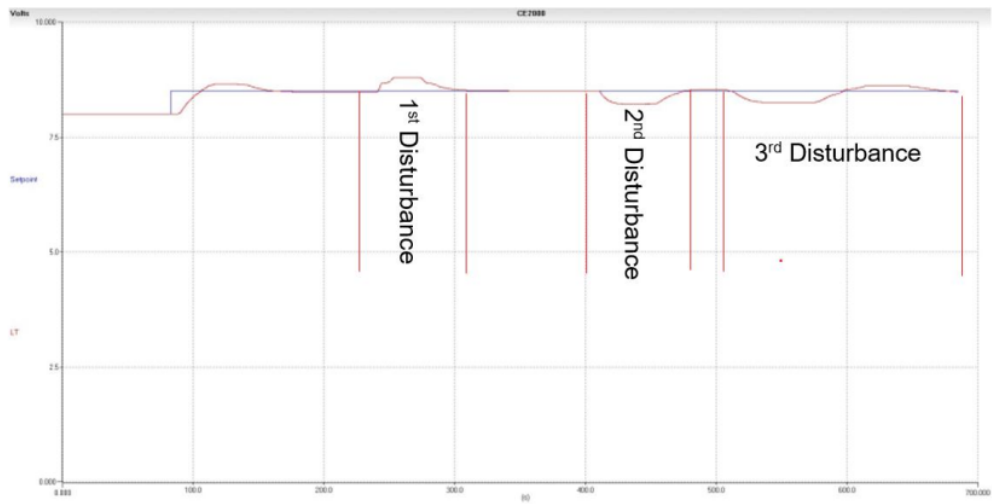


Figure 12; Level Disturbance

Level Control		
Instrument/Actuator	Operating Voltage	Comment
Level Transmitter	0-10V Output	Non-Linear
Proportional Valve	0-10V Input	0V = Closed, 10V= Open
Pump 2	0-10V Input	0V = No Flow, 10V = Max Flow

Table 6; Level Control Instruments and Actuators

Temperature Control		
Instrument/Actuator	Operating Voltage	Comment
Electric Heater	0-10V Input	0V = Heater off , 10V = 750W Max Power Nominal
PRT (Temperature Sensor)	0-10V Output	Linear 10 deg per volt
Pump 1	0-10V Input	0V = No Flow, 10V = Max Flow
Cooler	0-10V Input	Variable fan speed

Table 7; Temperature Control Instruments and Actuators

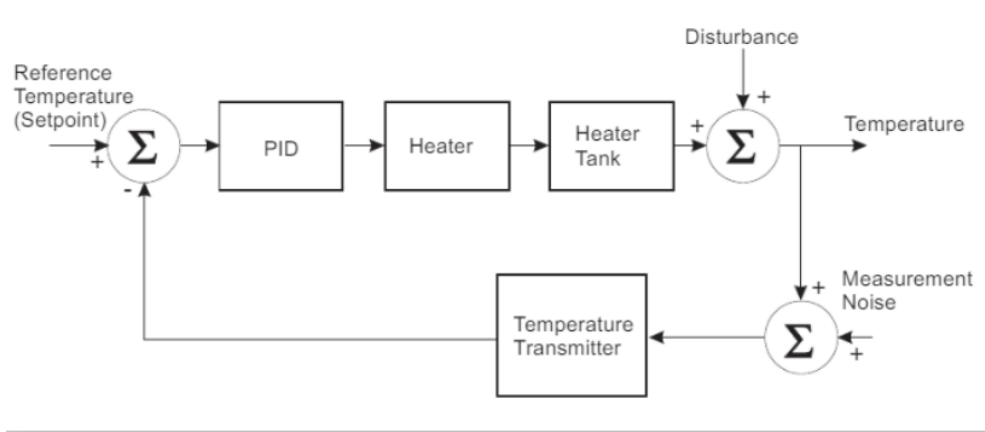


Figure 14; Control Block Diagram Temperature V2

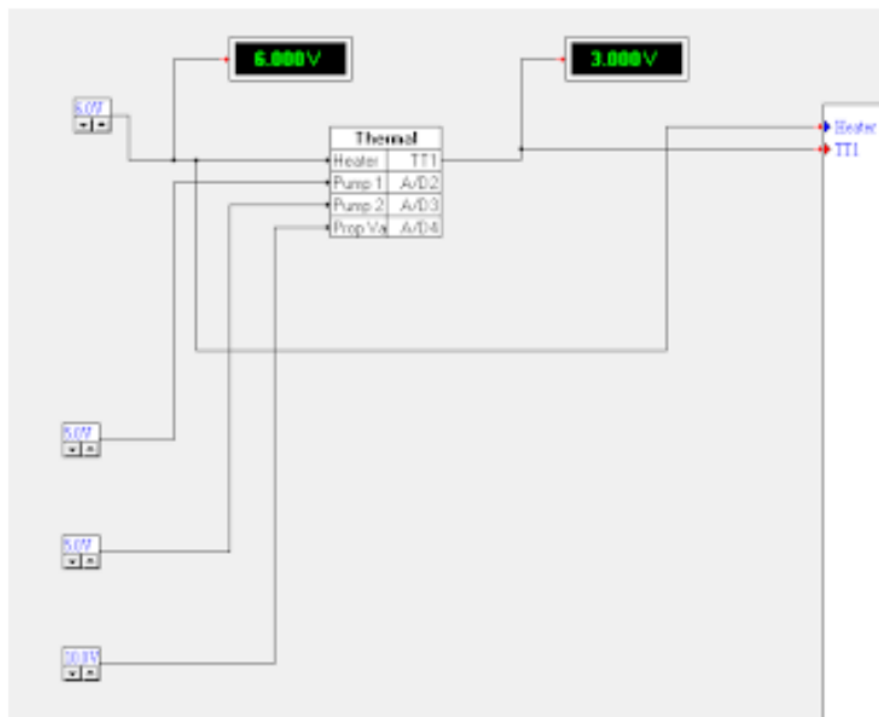


Figure 13; Temperature Set Up CE117

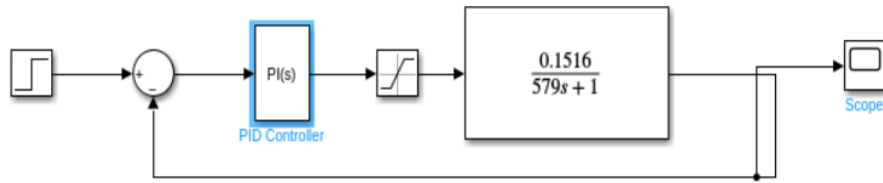


Figure 17; Simulated Mathematical Model

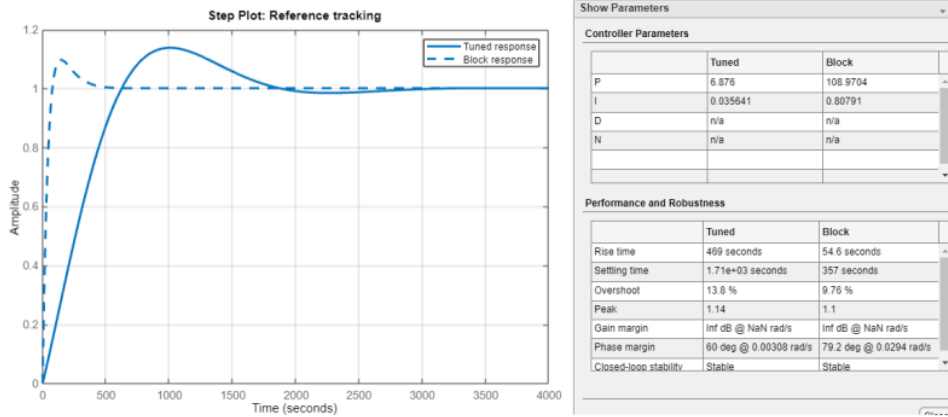


Figure 16; Tuned Responses

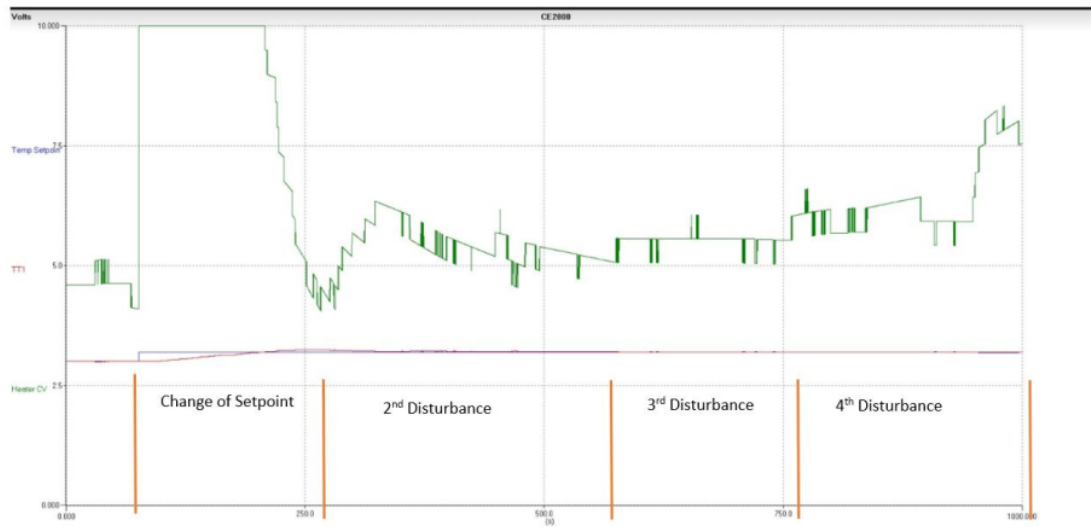


Figure 15; Disturbances Temperature

Instructor

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PAGE 1

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MATTHEW PERRY

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1. ENGAGEMENT WITH LITERATURE

 Report section 3 and 8 Good evidence of reading from a wide range of sources cited correctly and listed correctly using the Harvard method. 16/20

16

2. KNOWLEDGE AND UNDERSTANDING

 All report sections and particularly sections 3, 4 and 5 Clear evidence of understanding in your report overall and particularly in your Research and your explanation of your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments. 12/20

12

3. COGNITIVE AND INTELLECTUAL

 Report sections 4, 5 and 6 Good analysis of results in your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments with clear conclusions and recommendations presented. 13/20

13

4. PRACTICAL APPLICATION



Report sections 4 and 5 Good use of equipment and presentation of results in your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments. 14/20

14

5. TRANSFERABLE SKILLS



All report sections, but particularly sections 1, 2, 7 and word count penalty. Good report style, presentation, use of grammar, spelling and punctuation. Clear executive summary, good work plan and explanation of team working. Word count exceeded, penalty applied. 10/20

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