

1809806

by Richard Harrison

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1. Executive summary

The following assignment/paper documents research done into what flow, level, temperature control systems are and how they can operate within a process control system. The control philosophies that surround these control systems like PID and the Ziegler-Nichols method of calculating the values of K_p , K_i and K_d and how these values effect a process reaction curve. An investigation was performed into how the process control system in the G8 lab works and its schematic layout.

During the course of the practical part of this assignment/paper, process reaction curves for flow, level and temperature were produced using the process rig and calculation methods. These include the Caldwell and Ziegler-Nichols as well as a MatLab simulator and auto-tune plugin was used to determine good starting points for tuning the curve. Finer tuning needed to be done on the process rig for each practical. The results were then processed and evaluated. Conclusions were drawn looking into why errors occurred in the results and what was done to minimise them, and how the methods work within the system and relate to each other.

What were your conclusions?

2 Research and System Investigation

2.1 Flow control

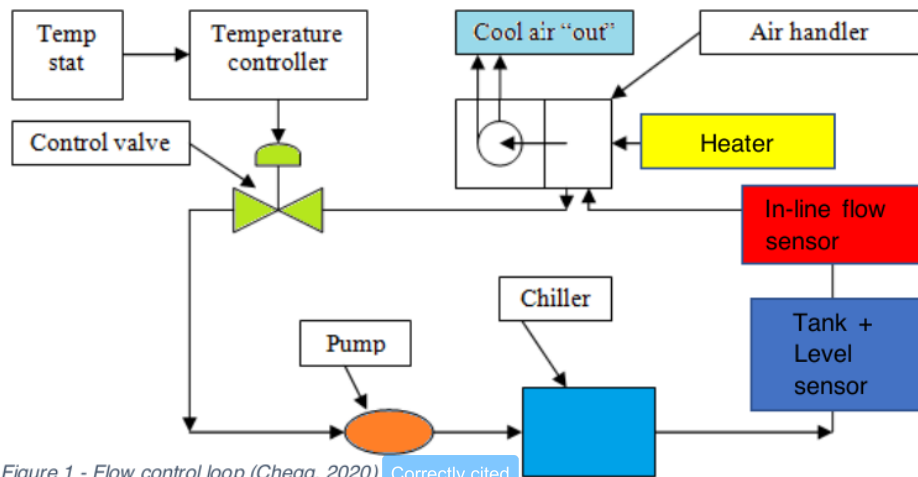


Figure 1 - Flow control loop (Chegg, 2020) Correctly cited

Figure 1 shows a simple control loop which would typically be found in industry. In this case a flow meter would be mounted in-line to provide feedback on flow and the pump would be used to increase or decrease the flow rate until the flow meter reads the correct amount. This control loop would be 2nd order in open loop and require PI&D control. Needing the second order transfer function:

$$\frac{Kw_n^2}{s^2 + 2\zeta w_n s + w_n^2}$$

Flow control can be categorised into open and closed control loops. With the difference being that open loop systems do not use a feedback mechanism whereas closed loop does. This means the system shown in figure 1 is a closed loop system since it has a flow sensor. Citation needed

2.1.1 Active flow control strategies

Active flow control strategies generally require more power compared to passive but in some cases can save more energy than they require. Strategies include:

1. **Streamwise travelling waves**. Depending upon the waveform applied, the drag can be greatly reduced since the waveform travels in the direction of flow.
2. **Blowing and suction**. By introducing jets that inject air into the water system, the effect of drag within the system is decreased and can be completely overcome, greatly increasing flow rate.
3. **Spanwise wall oscillations**. Depending upon the waveform used when oscillation is applied to the pipe walls, this method can increase drag as well as decrease it. Citation needed

2.1.2 Passive flow control strategies

The one method of passive flow control is called Riblets. This involves shaping the flow carrier i.e. pipeline with grooves to help direct flow. Drag reduction depends on the groove spacing and depth.

2.2 Level control

Level control is 1st order since flow is in and out, the system needs constant monitoring to maintain level. As shown in figure 1, the tank contains the level sensor which monitors the level and engages the pump and inlet to top up water in the tank when needed. Citation needed

However, when there is no flow out, its classed as an integrator.

Transfer function:

$$\frac{K}{\tau s + 1}$$

The system will pump water into the tank until the setpoint is satisfied. If the tank is a sealed unit the sensor may be an air pressure sensor which may feedback to a controller/PLC or it could be a simpler method like a ball-cock. Citation Needed

2.3 Temperature control

Temperature control is 1st order since heat is constantly being transferred in and out of the system and needs to be constantly monitored. The heater shown in figure 1 will have a temperature sensor mounted in the tank which feeds the controller. The controller will then switch the heater on when the water gets too cold. It will also activate the chiller if the water temperature is too high.

No heat out means its an integrator

Citation Needed

Transfer function:

$$\frac{K}{\tau s + 1}$$

2.4 Process control philosophies

Proportional Integral control is a control algorithm which is most often used in industrial settings where certain processes need to be closely, accurately and automatically monitored. Examples include flow rate, temperature or level.

First, the system has a set-point inputted and the controller receives input from the process variable through a sensor. An algorithm is then used by the controller to determine the

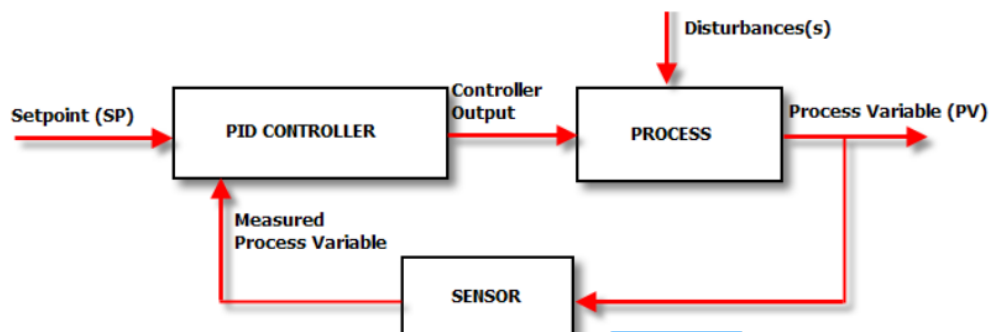


Figure 2 - PID Controller layout (Control solutions Minnesota, 2020) Correctly cited

difference between the setpoint and the process variable. If there is no difference, then the controller will do nothing. However, an unwanted disturbance could affect the process variables value and cause it to change. This means the setpoint and the process variable are different. If they are different the controller will power its output devices (for example a heater) to change the value of the process variable (e.g. a water boiler) until it matches the setpoint again. The process is shown in figure 1.

2.4.1 Ziegler-Nichols method

This method for a self-regulating control loop is used because it has a fast response time at the cost of stability. But the stability can be improved by adjusting the required response time. This tuning method can be used for controlling pressure, temperature, level and flow and is able to respond to disturbances in normal operation quickly. When used in an integrating process, the process variable will stabilize at one controller output. This means it is vital that the controller output is set at the point of equilibrium because if it is not, the process will climb or fall indefinitely since this is the only point at which the process can remain stable. An example of this method used for PID level control is shown in figure 3.

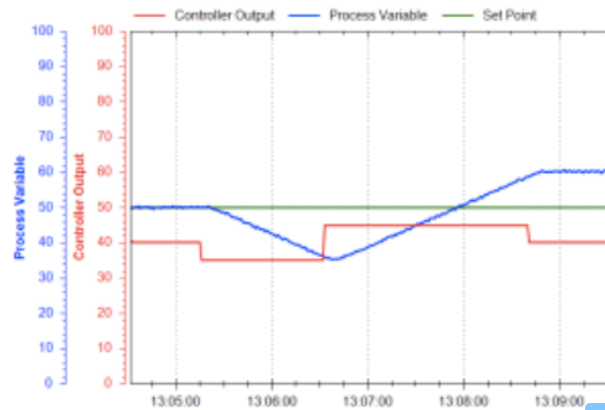


Figure 3 - Ziegler-Nichols level PID control (Dataforth, 2020)

This method has four major characteristics:

- Rise time: This term refers to the time taken for the output to increase beyond 90% of the amount specified for, for the first time.
- Settling time: The time taken for the system to reach steady state.
- Overshoot: This refers to the peak value compared to the value at steady state.
- Steady state error: This is the difference between the desired output of the system and the actual output with PID control.

Effects of changing PID values				
Part	Rise time	Settling time	Overshoot	Steady state error
Proportional	Decreases	No change	Increases	Decreases
Integral	Decreases	Increases	Increases	Cancels out
Derivative	No change	Decreases	Decreases	No change

Table 1 - Effects of changing PID values

For general use with regards to table 1, K_p is used to decrease rise time, K_i is used to cancel out the steady state error and K_d to reduce the overshoot and the settling time. However, tuning using these factors can never be 100% perfect since each of the three parts directly effects one or more other factor. Therefore, it can only be tuned to get close to the ideal output which is where the Ziegler-Nichols method is used.

2.5 System investigation

P&ID or Process and Instrumentation diagram shows the layout of the system as a schematic. **(shown in appendix)** It allows a user to see all the system parts, how they are connected, general system layout and how they function within their loops and how they contribute to the overall process. This allows for easier troubleshooting and monitoring of the process.

With reference to the diagram 1.0 and 2.0 shown in the appendix.

Water travels through the system by passing through solenoid-controlled gate valves. Either V516 which bypasses the radiator or V515 which routes water through the radiator. Flow is controlled by FC535. This uses the process variable from FT535 to calculate the control variable which> Depending on the value of the control variable the flow controller will then increase or decrease the pump amplifier (LY541) until the flow rate indicated by FT535 matches the setpoint. If for example gate V515 is opened, water is pulled past the radiator by the pump (DC pump P1) to the processing operation. Another three valve gates VF510, 511, 512 and VF531 control access to the other chambers which are opened by FC531. While FT531 provides the controller with flow data.

A heater element heats the water and the temperature sensor TT511 informs the PID controller TC511 what the temperature of the water is. The controller creates a control variable which will vary the solid-state relay for the heater using pulse-width-modulation depending on the setpoint. However, this will only happen if the “water low level” interlock LS542 allows it. Otherwise, the heater cannot run for safety reasons. If TC511 determines the water requires cooling, In order to cool the water in the system the gate V516 will close and V515 will open to route water through the radiator. In this case depending upon radiator fin density effecting flow rate the controller may increase the pump speed depending upon the input from FT535. The level controller LC541 uses the input received from LT541 as a process variable and either activates the pump amplifier LY541 to top up the tank or opens V500 to drain it. From B1 (cleaning) into the buffer/holding tank B0. B0 also has a level switch interlock LS541 to ensure the pump does not run dry.

3 Flow control system

3.1 MatLab process reaction curve modelling

The data obtained is from an open loop run on the CIM system in G8. Using this data, a process reaction curve can be created (figure 16 appendix).

From peak (Figure 16): 73% of 96.8363 = 70.69

At 70.69, $X = 721 = ty$ (Figure 15)

$$\tau_1 + \tau_2 = \frac{0.721}{1.32} = 0.5462$$

$$t_x = \frac{\tau_1 + \tau_2}{2} = \frac{0.5462}{2} = 0.2731 \text{ (Figure 17)}$$

$$X = \frac{31.051}{96.7985} = 0.321$$

By using the Caldwell graph (Figure 18 appendix) and plotting $X=0.321$ across until it intersects the rise, this gives the value of:

$$\frac{\tau_2}{\tau_1 + \tau_2} = 0.835$$

$$\text{Therefore, } \tau_2 = 0.835 \times 0.5462 = 0.4561$$

$$\text{and, } \tau_1 = 0.5462 - 0.4561 = 0.0901$$

In order to work out the General solution:

$$\frac{1}{0.4561 \times 0.0901} = 24.33$$

For General solution:

$$0.5462 \times 24.33 = 13.29$$

$$\text{Therefore, } G(s) = \frac{24.33}{s^2 + 13.29s + 24.33}$$

See figures 19, 20 and 21 (appendix). These show how the MatLab program interpreted and used the calculated values. The resultant curve closely matches the original reaction curve proving the calculations are correct.

3.1.1 Tuning

By adjusting the values programmed in MatLab to produce the results shown in figure 19 (appendix), the results can be fine-tuned to better match the original curve. (figure 4). The corresponding MatLab program is shown in figure 22 (appendix). With reference to the general solution, adjusting the numerator will move the tuned curve up or down, the “s” value will move the curve diagonally between the top left and bottom right corners while the last value changes the point at which the curve reaches steady state.

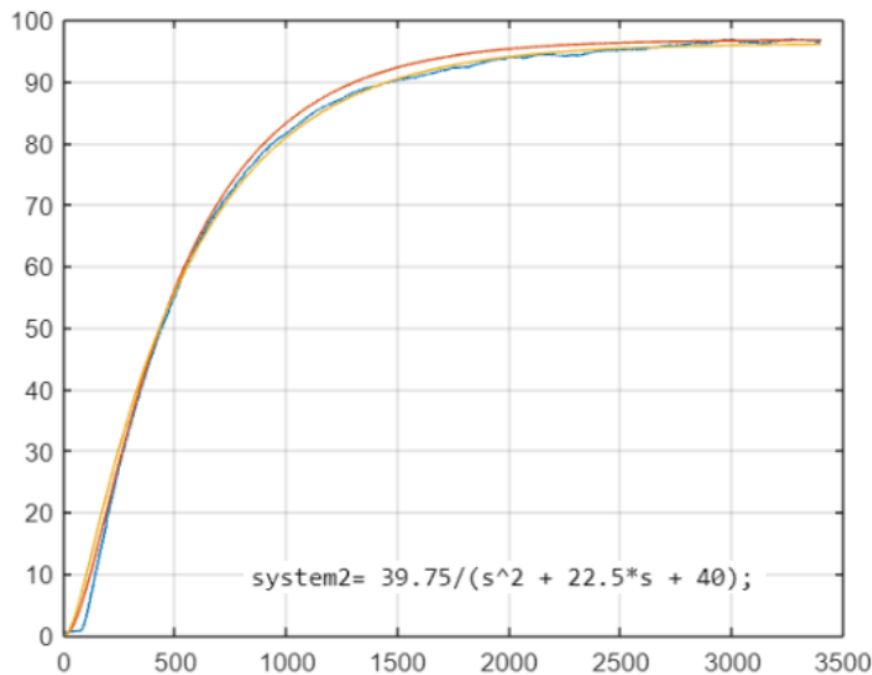


Figure 4 - Tuned, calculated and original process reaction curve

Figure 4 shows all three reaction curves on the same graph along with the tuned values. The **original**, **calculated** and **tuned** circuits. The tuned curve is as close to the original as possible while having a shorter delay. Possibly meaning greater efficiency or more leeway for greater accuracy if the delay is allowed to increase.

When tuned using the MatLab PID tuner plugin the results give 1.6564 for Kp, 0.0050617 for Ki and 76.263 for Kd. (figure 5 page 9). These values can be used as a starting point on the process system in G8. Figure 5 shows a 6.3% overshoot, 0.478 second rise time and 1.65 second settling time. The graph can be tuned to produce a more aggressive curve, proving what was talked about in the research. (figures 6 + 7 page 10,11)

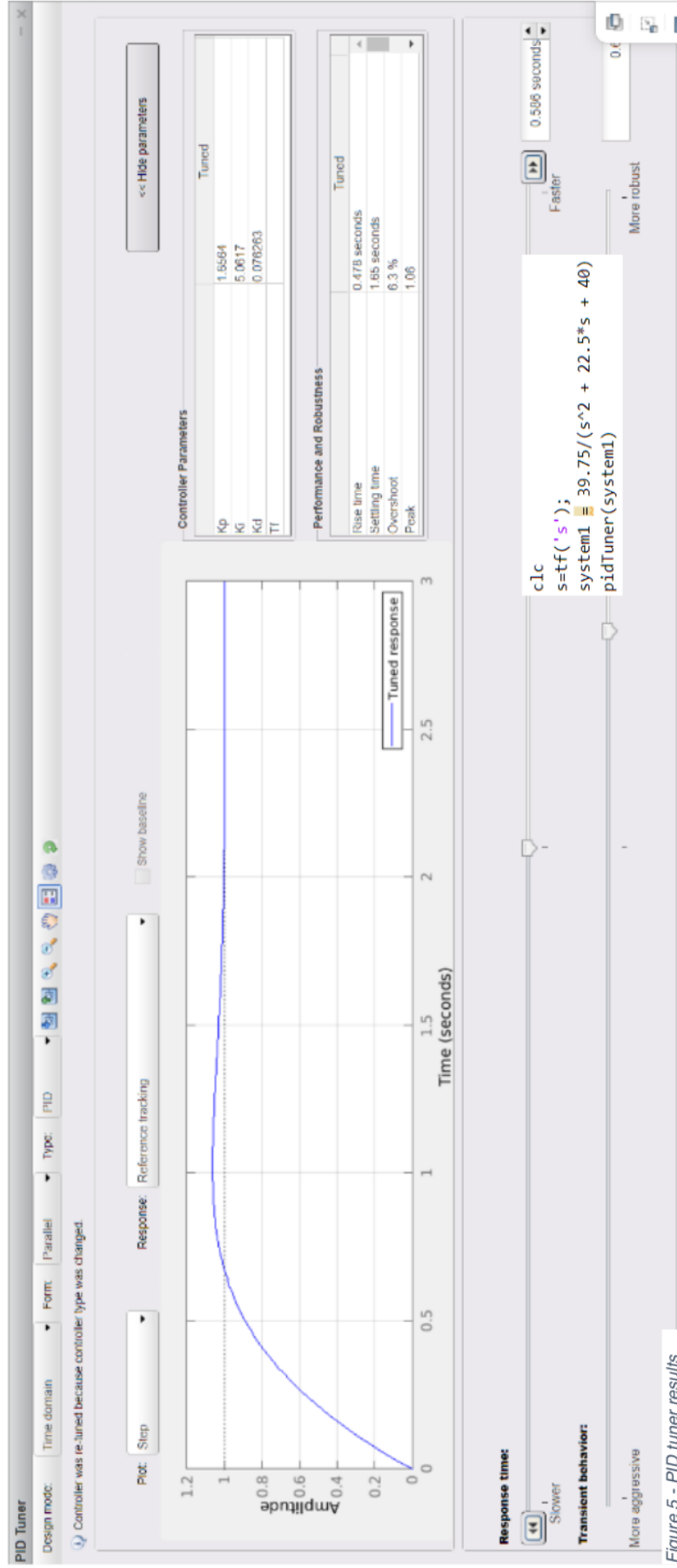


Figure 5 - PID tuner results

Faster response (0.139 seconds)

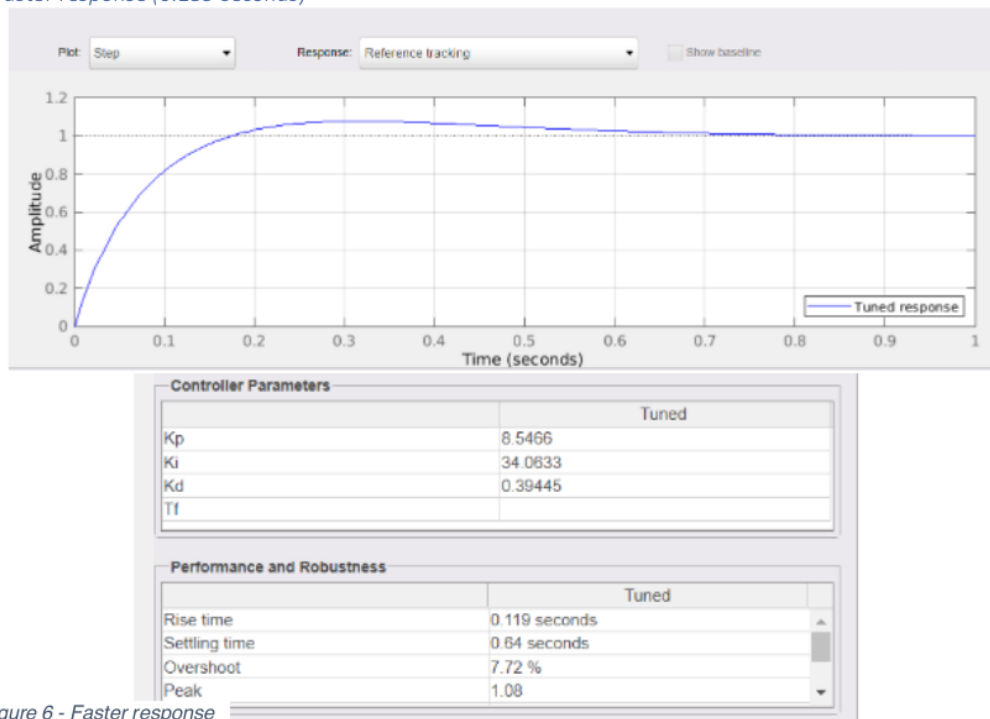


Figure 6 - Faster response

The faster response applied gives a faster rise and settling time but at the cost of a greater overshoot and increased PID values.

Slower response (0.96 seconds)

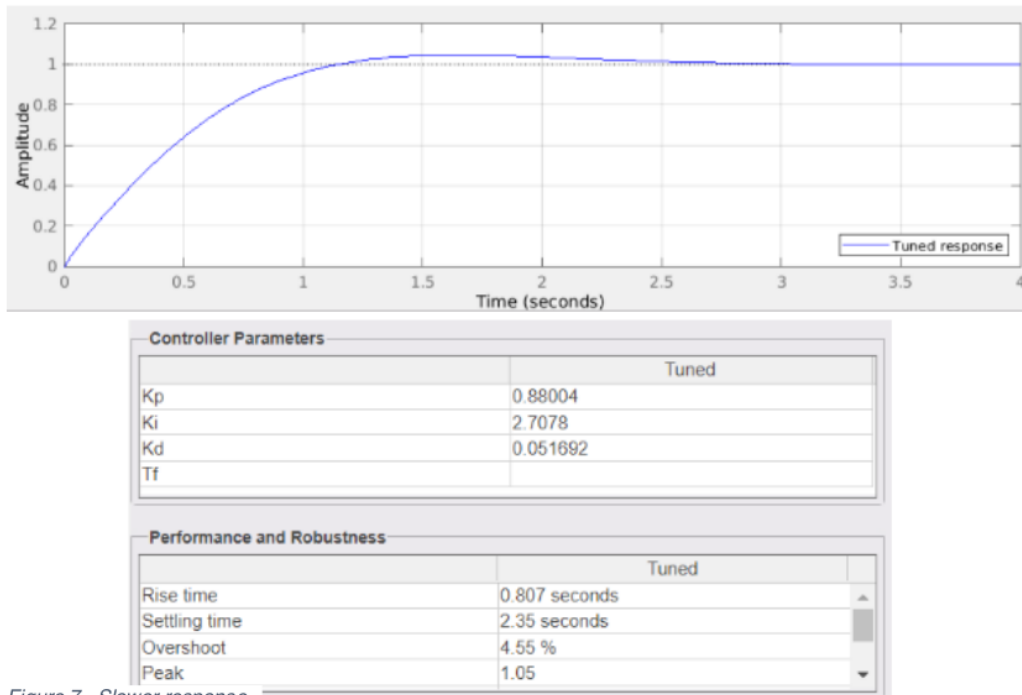


Figure 7 - Slower response

A slower response reduces overshoot while the peak stays roughly the same at the cost of a slower reaction curve overall. This shows how a faster system that responds quickly will potentially be more unstable and a large overshoot could potentially cause damage.

For rlocus:

$$s = \frac{-22.5 + \sqrt{22.5^2 - 4 \times 1 \times 40}}{2 \times 1} = \frac{-22.5 + j\sqrt{506.25 - 160}}{2} = -11.25 + j18.61 = 7.36$$

Or:

$$s = \frac{-22.5 - \sqrt{22.5^2 - 4 \times 1 \times 40}}{2 \times 1} = \frac{-22.5 - j\sqrt{506.25 - 160}}{2} = -11.25 - j18.61 = -29.86$$

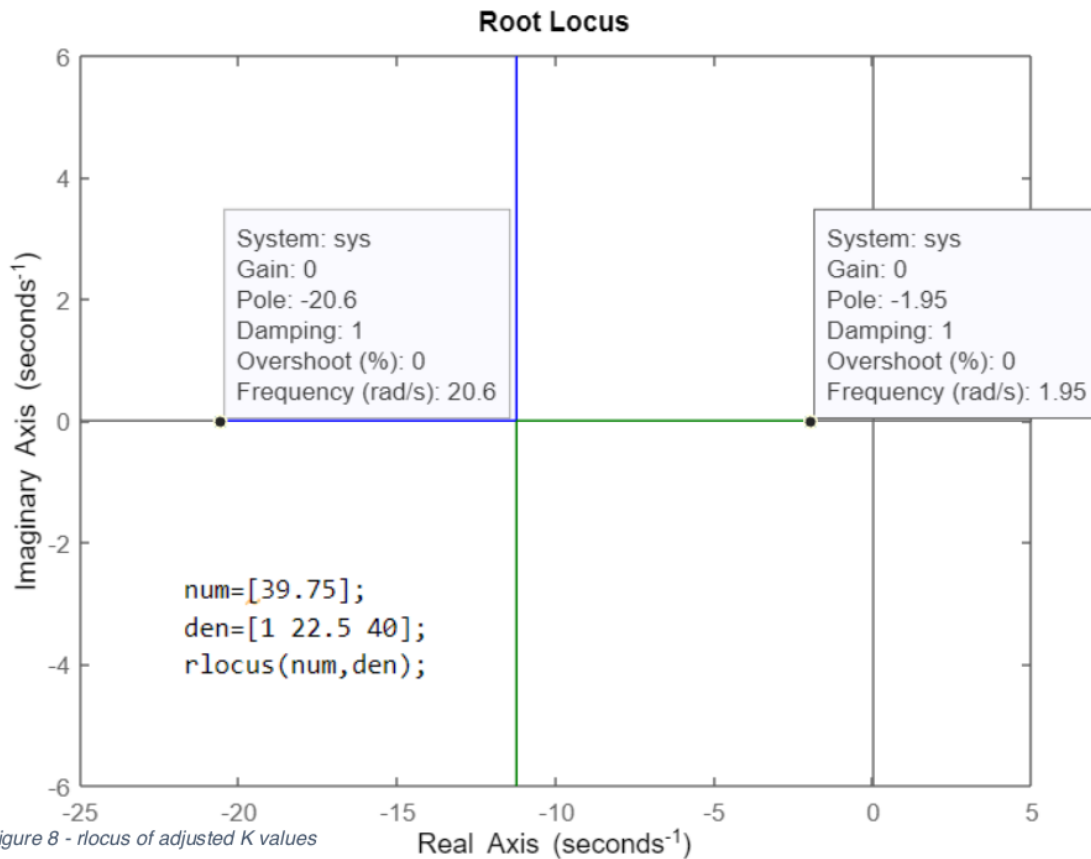


Figure 8 - rlocus of adjusted K values

From figure 8, the results from the tuned values give stable and overdamped poles, because both poles are on the left hand plane and on the j-axis.

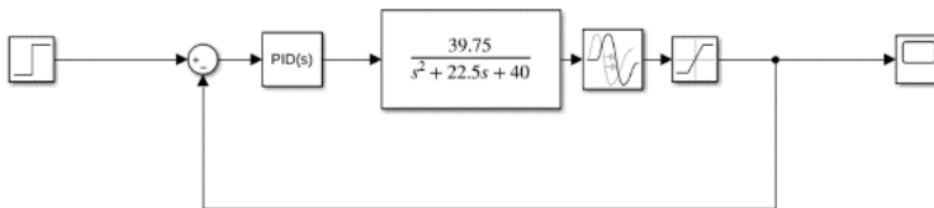


Figure 9 - Tuned Simulink

Once the tuned values were put into the process station in G8 the PID values needed some adjustment and further tuning to achieve results that had reduced errors. The errors/ spikes/ instability of the pump when using the generated values from the tuning in MatLab may be the result of the pump being non-linear. As a result, figure 10 shows the process station pump reaction curve with PID values of:

- $K_p = 0.9$
- $K_i = 0.002$
- $K_d = 8.4$

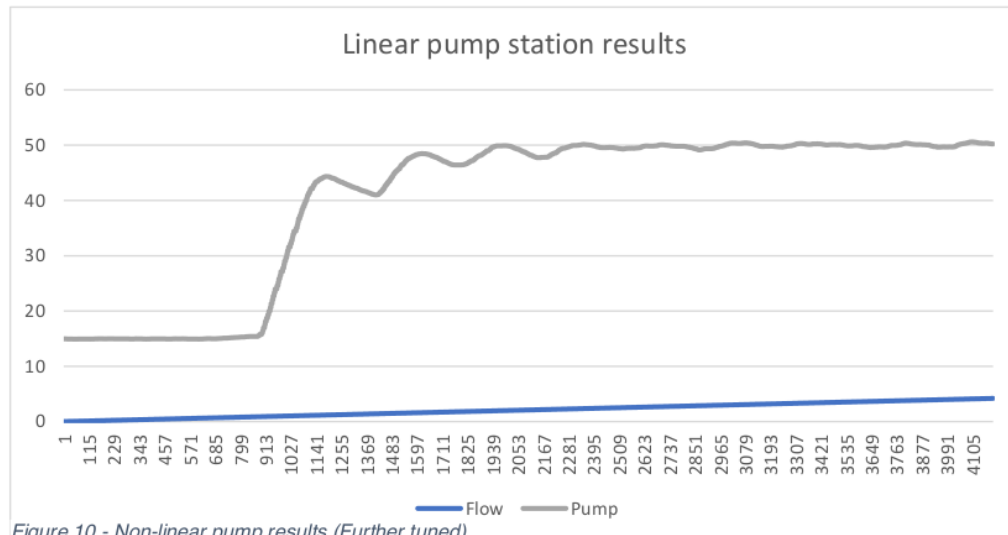


Figure 10 - Non-linear pump results (Further tuned)

Regarding figure 10, once fine-tuned on the process rig the pump had no overshoot but seemed unstable when nearing its peak this may could mean more tuning is required instead of a non-linear pump to improve the curve.

3.1.2 Zeigler-Nichols method to find PID values

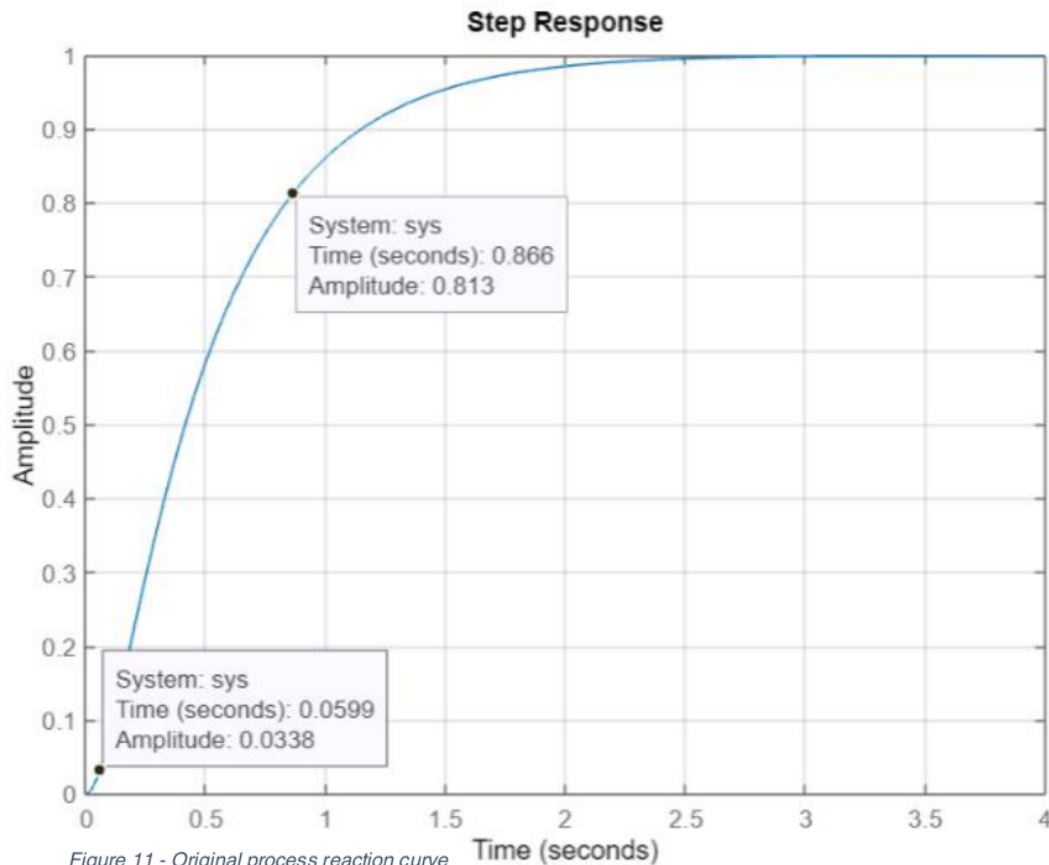


Figure 11 - Original process reaction curve

Figure 11 shows the original process reaction curve produced. Before it was tuned in any way. The following equations go through solving the PID values using Zeigler-Nichols.

$$\text{Lag time} = 0.0599 \text{ seconds}$$

$$T = 0.866 - 0.0599 = 0.8061 \text{ seconds}$$

$$\text{Reaction rate} = \frac{1}{0.8061} = 1.241$$

$$K_p = 1.2 \frac{0.8061}{0.0599} = 16.15$$

$$K_i = \frac{16.15}{2 \times 0.0599} = 134.81$$

$$K_d = 0.5 \times 16.15 \times 0.0599 = 0.484$$

Shown in figure 12 are the results for K_p , K_i and K_d . The controller parameters show a different set of results when compared to the calculated values using the Zeigler-Nichols method. The overall reason for this is that there is an error somewhere. Either in the calculations or in the program. From this it can be seen that different methods yield different results and a simple human error can throw all the results dramatically off course. It is unknown what has caused this error but the difference between the results because of it are substantial. However, the two methods are relatively similar. They both take samples of data from a reaction curve to produce results but use the data in slightly different ways.

The Zeigler-Nichols method takes samples and uses only the time (Y-axis) values to produce a set of results. Whereas the other method using Caldwell, originally uses the peak values (X-axis) and uses rise percentage points to produce a result.

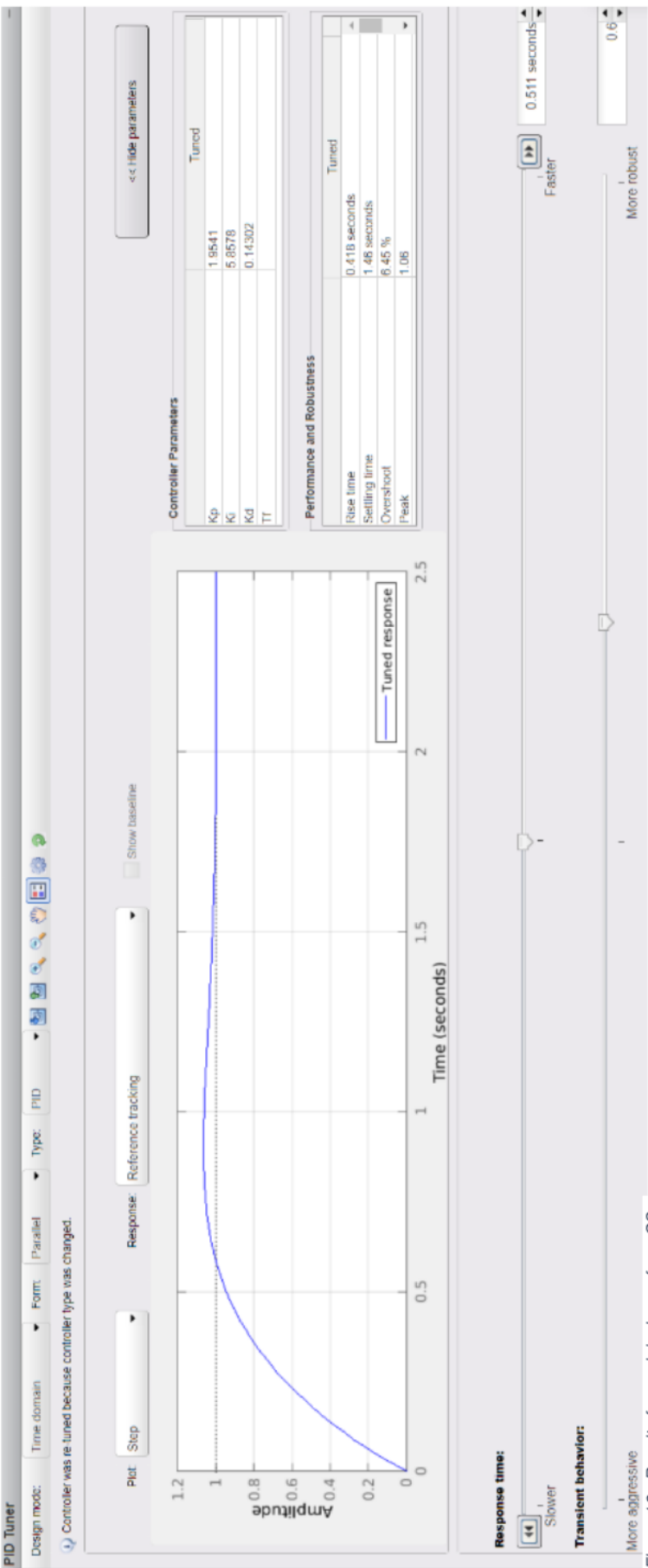


Figure 12 - Results from original waveform GS

4. Level control system

Once a process reaction curve was produced using the rig in the G8 lab, a transfer function could be created. The resultant graphs were shown in figure 23 and figure 24 (appendix).

Two samples were taken at points 195 (PV=3.98) and 60 (PV=17.95).

From the data obtained from the process rig:

$$\text{Gradient} = \frac{17.95 - 3.98}{195 - 60} = \frac{13.97}{135} = 0.103481 \text{ or } 0.104(3dp)$$

$$G(s) = \frac{0.104}{s}$$

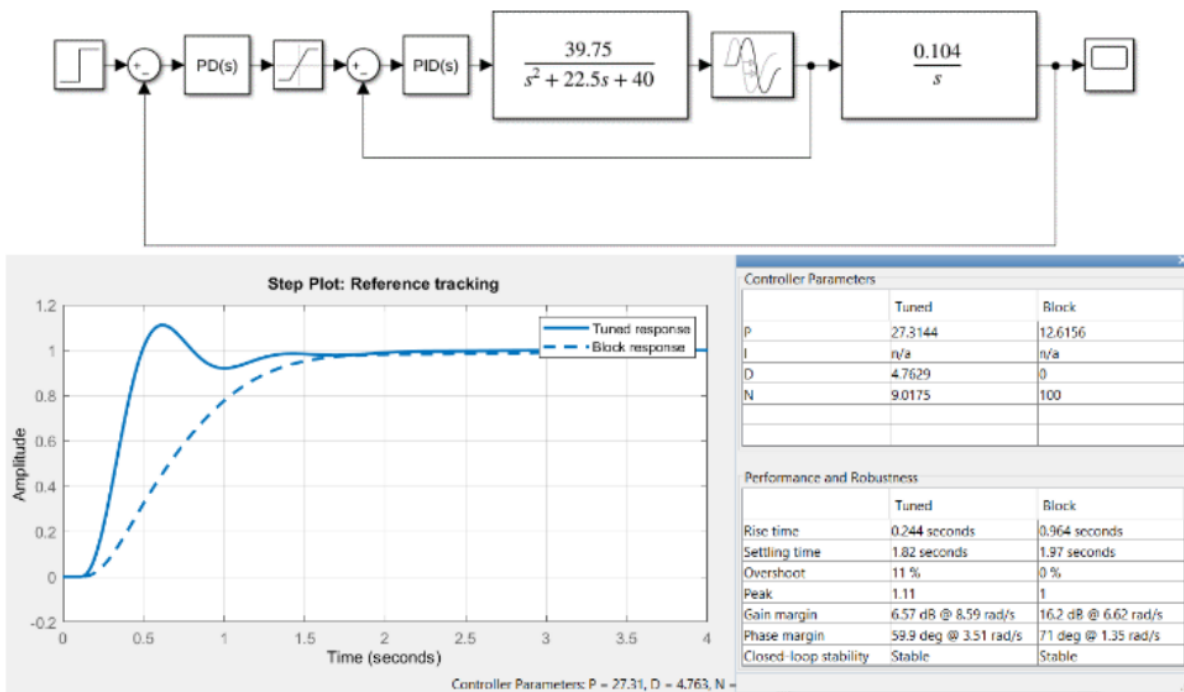


Figure 13 - Simulink model with Level transfer function inputted

Once the auto-tuned values from the MatLab simulator shown in figure 13 were produced they could be inputted into the process rig. The result of this is shown in figure 25 (appendix). With the values from the simulator an error value was created. This needs to be minimised by tuning the inputted values, which will allow the pump to run better increase the efficiency of the system. Figure 26 (appendix) shows the results after tuning the PID values where the error was reduced to around $1/10^{\text{th}}$ of its original value. Although, it is possible that the error could have occurred or been magnified by the fact that the gradient value was rounded to 3dp.

5. Temperature control system

Temperature control has no inner loop for flow, this analysis is incorrect

For this experiment, the process rigs cleaning tank labelled B1 in appendix figure 1.0 (appendix) was filled with approximately 20cm of water. The heaters were activated and set to 100% to create the reaction curve shown in figure 27 and figure 28 (appendix). From this data the gradient and resultant transfer function can be derived to create accurate MatLab results. Two samples of the graph were taken. One near the low point 729 (PV=16.76) and one near the peak 299 (PV=48.93).

$$\text{Gradient} = \frac{48.93 - 16.76}{729 - 299} = \frac{32.17}{430} = 0.07481 \text{ or } 0.075(3dp)$$

$$G(s) = \frac{0.075}{s}$$

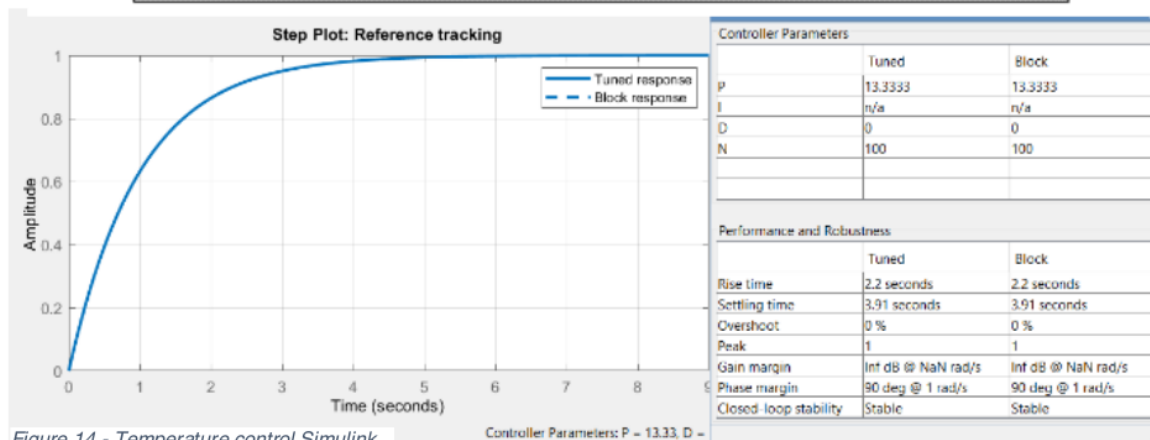
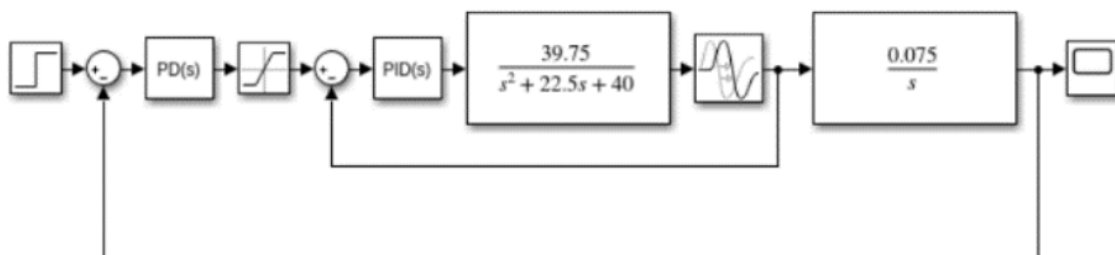


Figure 14 - Temperature control Simulink

Figure 29 and figure 30 (appendix) show the results once the auto-tuned values from MatLab (figure 14) were inputted into the process rig. Figure 29 (appendix) shows the results of the first run. The values clearly needed more tuning to create a better graph. Figure 30 (appendix) shows the results after the extra tuning. The need for this tuning may be because the gradient was rounded to 3dp instead of being used in its purer form. However, in conclusion the results from MatLab cannot be used as the running values since it is a simulator. It is best to use it to find good starting values and fine-tune once the process rig is running.

6. Conclusions and recommendations

The practical results match the values predicted by both the MatLab simulator and the calculations except in a few instances. During flow control the process rig gave unexpected results that were possibly due to the Linear pump used or it could have been because the curve required more tuning. When used for the calculations, the Zeiger-Nichols method yielded results which differed greatly from the results given by both the other calculation method and the simulator. So much so that it is difficult to determine whether it is due to human error in the calculation or simulation. However, two different methods will never be the same in their results but should end up reasonably close so to conclude, there must be an error somewhere. The methods themselves are not so different. Their main difference is that the Zeiger-Nichols takes samples of the curve in terms of its time and rise period. Whereas the Caldwell differs in that it uses certain percentage points of amplitude to determine the outcome of the calculation.

In the case of level and temperature control the calculation method is relatively the same for both. Even though they are very different things.

If the experiment was to be redone, I would recommend using a third calculation method for flow and another for both level and temperature. Also, updating or re-calibrating the various pieces of sensing equipment may improve the results overall.

The discrepancies and need for fine tuning of the curve once put back into the process rig shows how the MatLab simulator and auto-tune feature can only work as far as calculations go and determine its results with "best case" scenario values. Real world applications like the process rig will always require fine-tuning so the simulator can only be used to find a good starting point. Not a fine-tuned value. But it also shows how big a factor, the parts and pieces of equipment that go into making a system such as this are. No matter how minute a difference they may seem to make.

7. Team working

During this assignment, we have worked well as a team during this difficult time. Communicating well as a team and working through problems. During practical experiments we co-ordinated our actions to get the best results and as a result, use our limited time effectively.

8. Works Cited

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9. Appendix

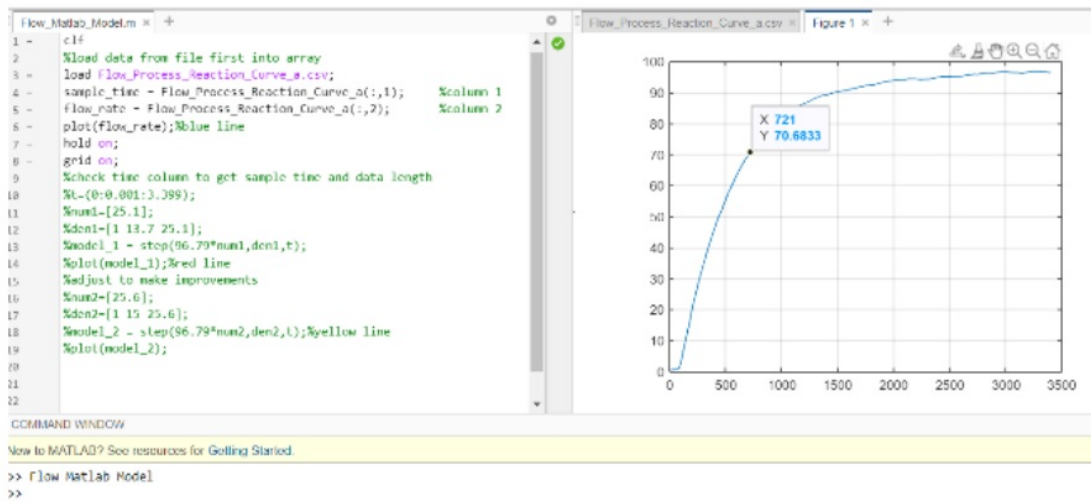


Figure 15 - ty value

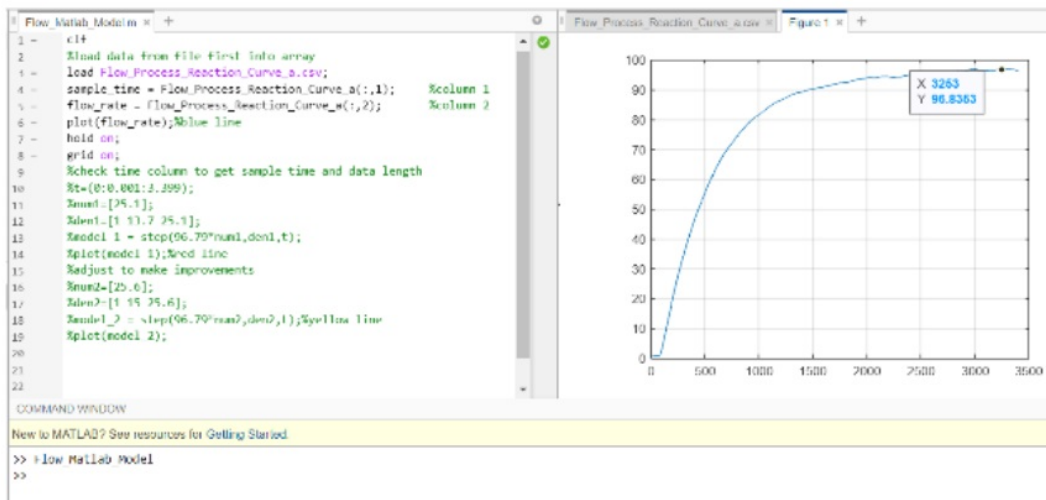


Figure 16 - Peak value

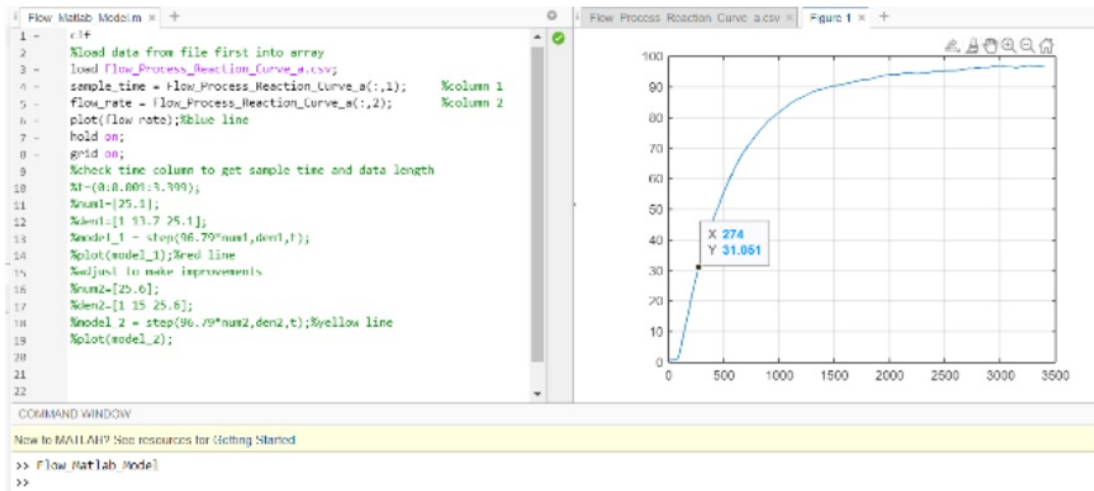


Figure 17 - tx value to find X

Caldwell Reference Graph

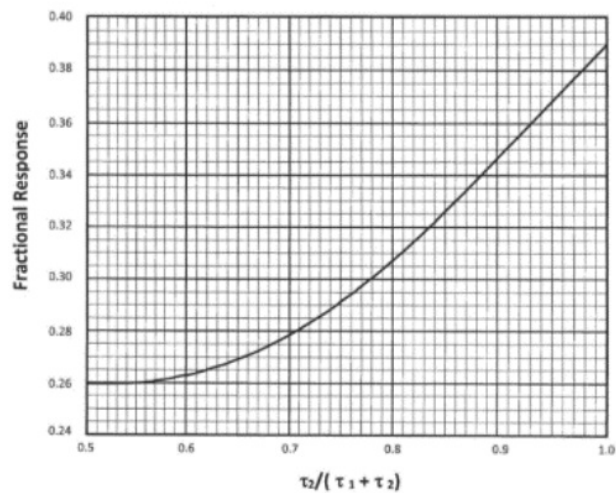


Figure 18 - Caldwell graph. Using 0.26 set value

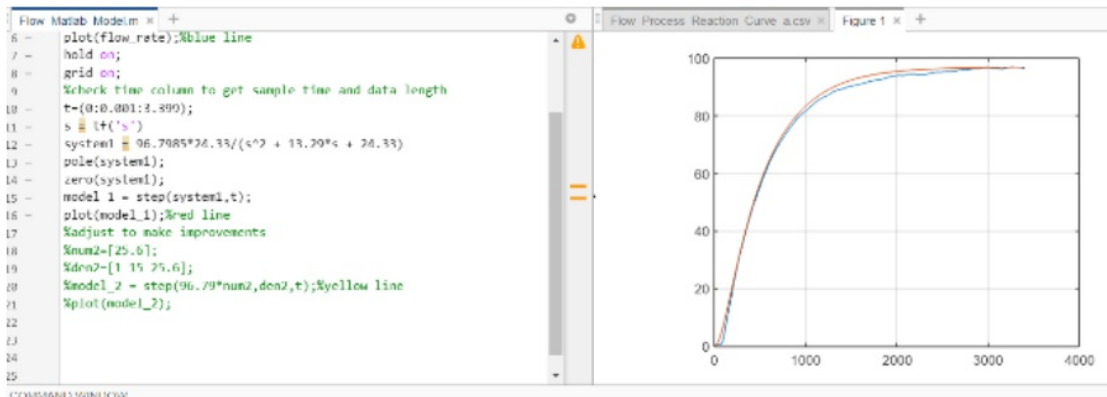


Figure 19 - Calculated values against original reaction curve

```

Flow_Matlab_Model.m | Flow_Process_Reaction_Curve_a.csv | Figure 1
COMMAND WINDOW
New to MATLAB? See resources for Getting Started.

system1 = 96.7985*24.33/(s^2 + 13.29*s + 24.33)

>> Flow_Matlab_Model

s =

s

Continuous-time transfer function.

system1 =

      2355
-----
s^2 + 13.29 s + 24.33

Continuous-time transfer function.

>>

```

Figure 20 - Matlab calculations following reproduced graph

Lesson 9

Highest point on graph

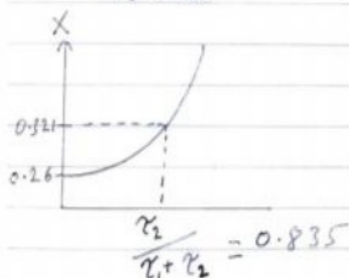
$$73\% \text{ of } 96.7985 = 70.66$$

$$\text{At } 70.66, X = 721$$

$$t_y = 0.721 \quad x_1 + x_2 = \frac{t_y}{1.32} = \frac{0.721}{1.32} = 0.5462$$

$$t_x = \frac{x_1 + x_2}{2} = \frac{0.5462}{2} = 0.2731$$

$$X = \frac{31.051}{96.7985} = 0.321$$



0.26 is set on Caldwell graph

$$\begin{aligned} \text{Therefore: } x_2 &= 0.835 \times (x_1 + x_2) \\ &= 0.835 \times 0.5462 \\ &= 0.4561 \end{aligned}$$

$$x_1 = (x_1 + x_2) - x_2 = 0.5462 - 0.4561 = 0.0901$$

So:

$$G(s) = \frac{1/x_1 x_2}{s^2 + (x_1 + x_2)s + 1/x_1 x_2} \rightarrow \frac{1}{x_1 x_2} = \frac{1}{0.0901 \times 0.4561} = 24.33$$

$$\rightarrow \frac{(x_1 + x_2)}{x_1 x_2} = \frac{0.5462}{0.0901 \times 0.4561} = 13.29$$

$$G(s) = \frac{24.33}{s^2 + 13.29s + 24.33}$$

Figure 21 - Calculations from notes

```

clf
%load data from file first into array
load Flow_Process_Reaction_Curve_a.csv;
sample_time = Flow_Process_Reaction_Curve_a(:,1);    %column 1
flow_rate = Flow_Process_Reaction_Curve_a(:,2);      %column 2
plot(flow_rate);%blue line
hold on;
grid on;
%check time column to get sample time and data length
t=(0:0.001:3.399);

s=tf('s');
system1 = 96.7985*24.33/(s^2 + 13.29*s + 24.33)
pole(system1)
model_1 = step(system1,t);
plot(model_1);%red line
%adjust to make improvements
system2= 39.75/(s^2 + 22.5*s + 40);
pole(system2);
model_2 = step(96.79*system2,t);%yellow line
plot(model_2);

```

Figure 22 - Tuned, calculated and original curves program

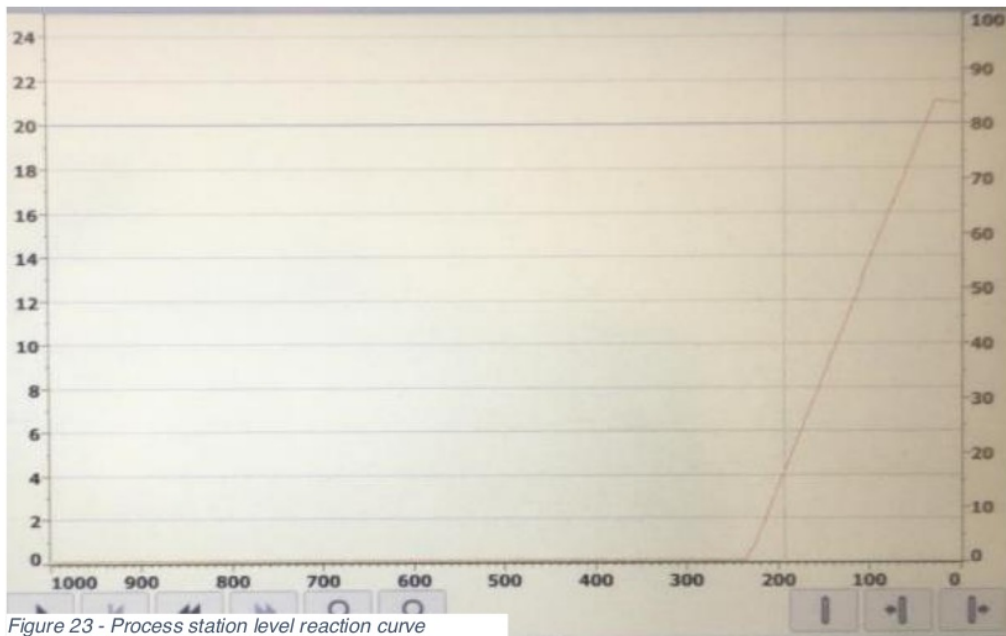


Figure 23 - Process station level reaction curve

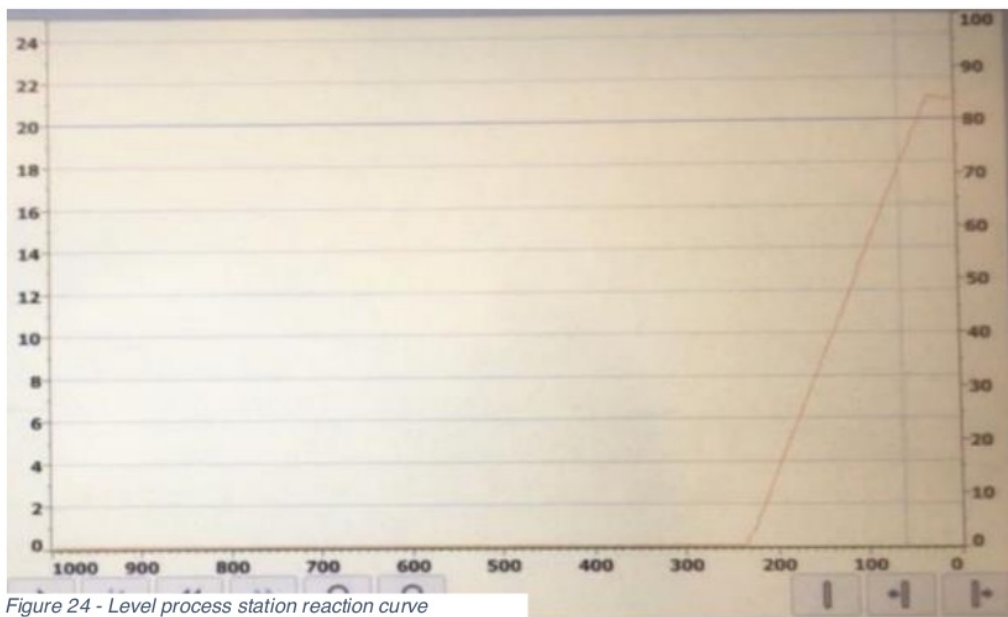
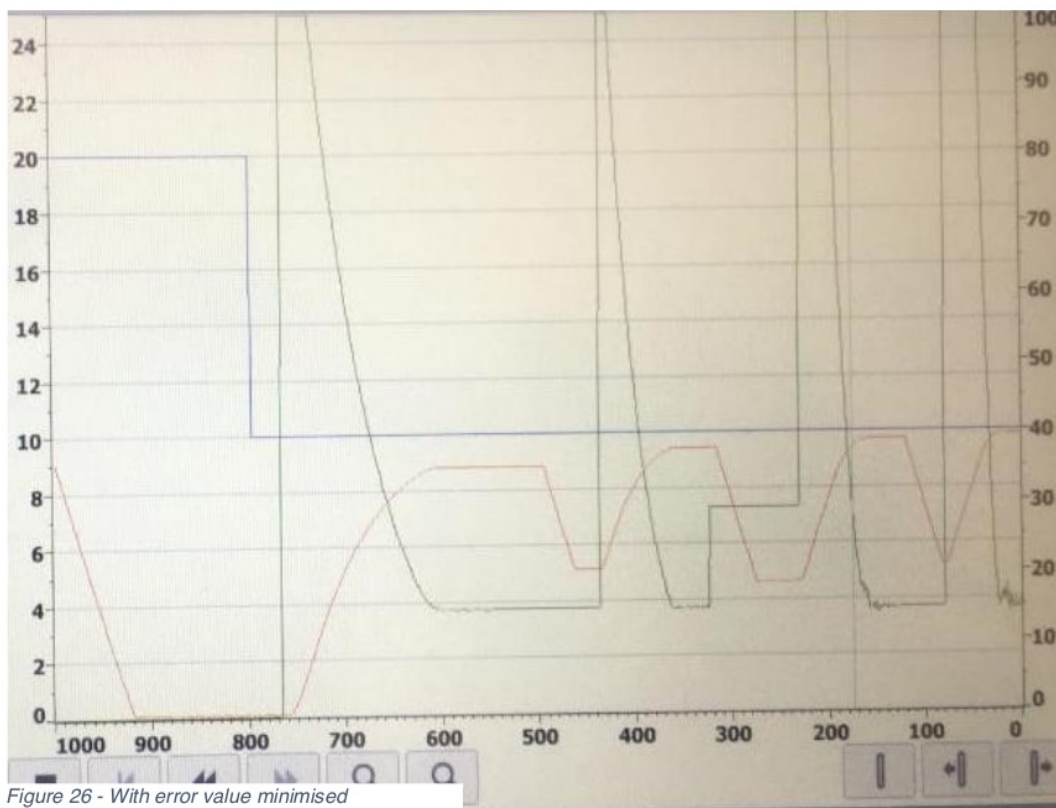
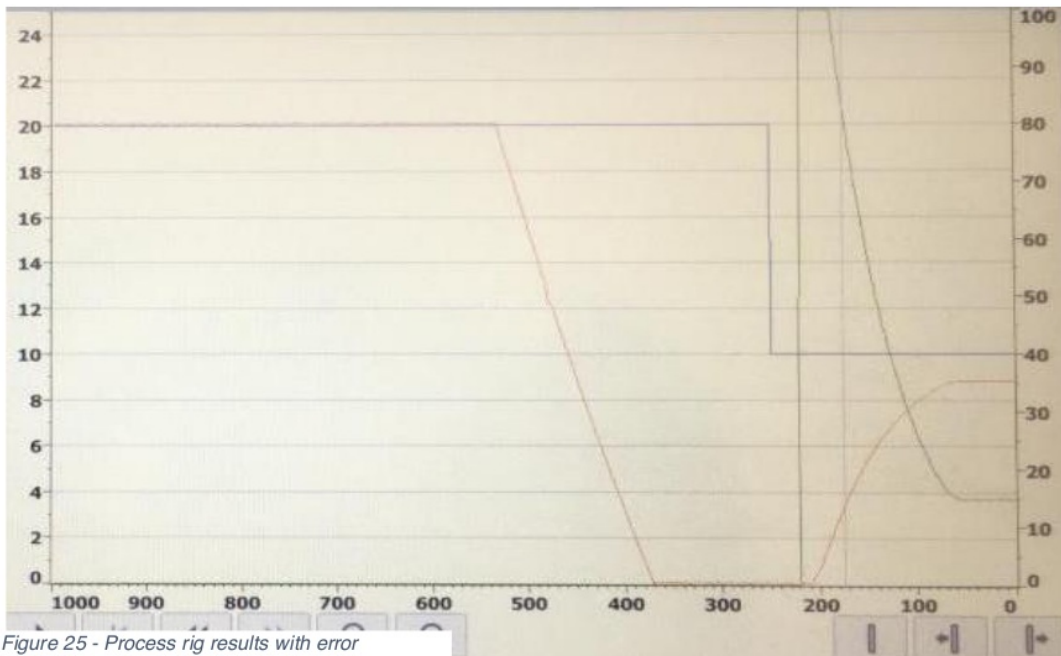
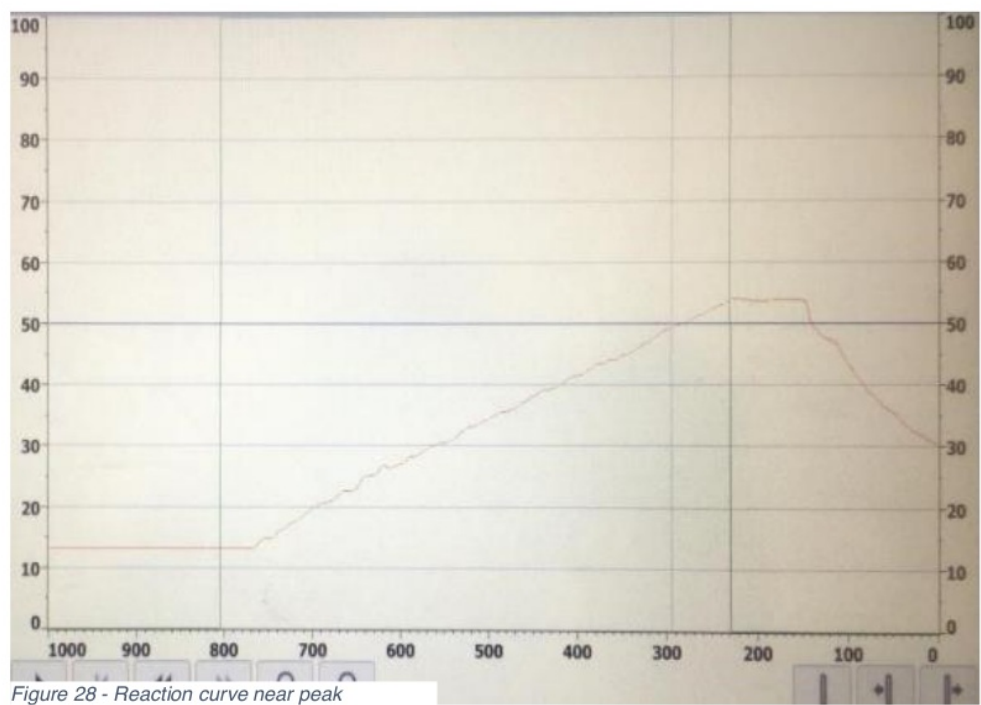
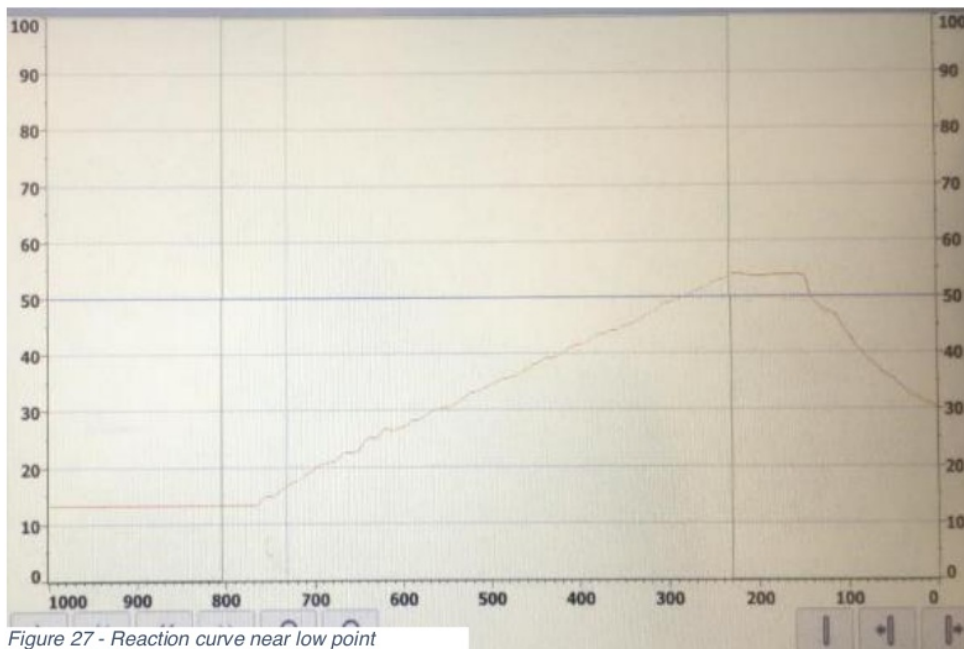
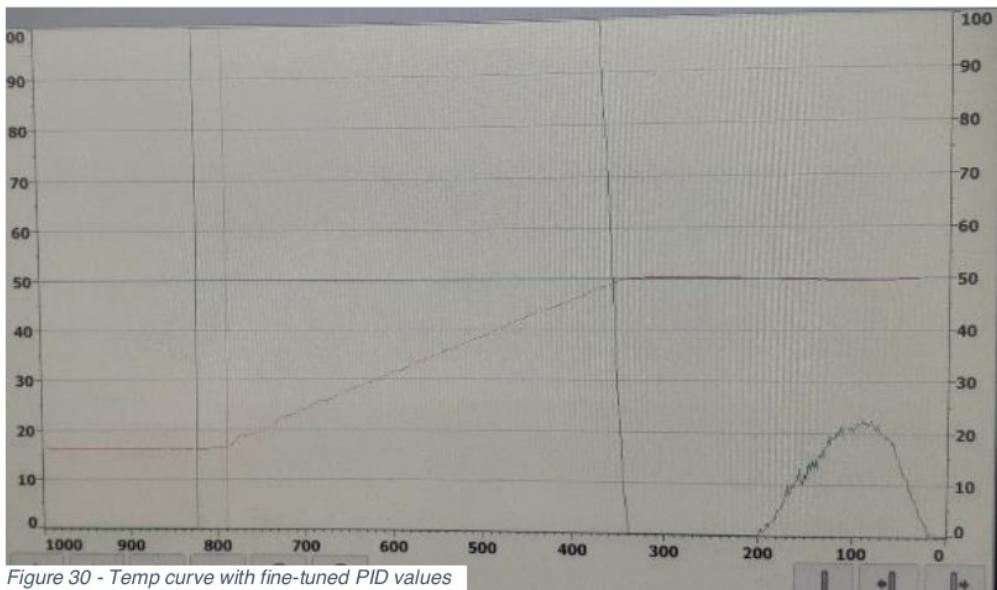
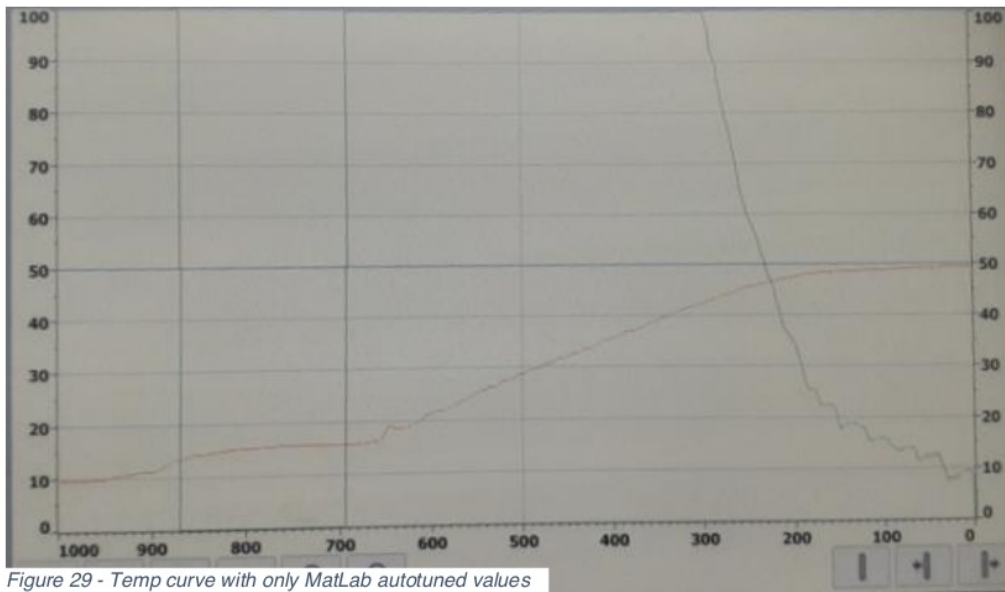


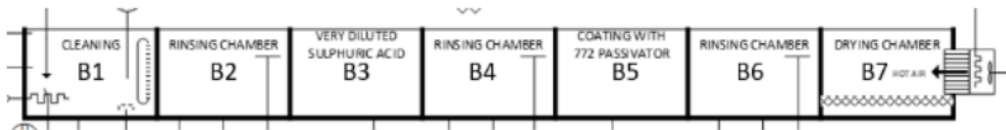
Figure 24 - Level process station reaction curve







2.0



B1. Cleaning with hot water

B2. Rinsing with cold water

B3. Cleaning with very diluted sulphur acid

B4. Rinsing with cold water

B5. Coating with 772 passivator

B6. Rinsing with cold water

B7. Drying chamber with hot air

TC535 – Flow control of water into tank B1

TC511 – Temperature control of water in tank B1

TC541 – Level control of water in tank B1

TC531 – Flow control of water into tanks

FINAL GRADE

GENERAL COMMENTS

Instructor**60**/100

PAGE 1

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

Text Comment. What were your conclusions?PAGE 5

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

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Text Comment. Temperature control has no inner loop for flow, this analysis is incorrect

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Correct method of listing.

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

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**RICHARD
HARRISON**

60

1. ENGAGEMENT WITH LITERATURE



Engagement with an appropriate range of literature, including sources retrieved independently. Some over-reliance on texts. Referencing may show minor inaccuracies or inconsistencies. (10/20)

10

2. KNOWLEDGE AND UNDERSTANDING



Knowledge is reasonably extensive. Exhibits very competent critical understanding of the well-established concepts and principles of the subject and the main methods of enquiry. Breadth and depth of knowledge. (12/20)

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3. COGNITIVE AND INTELLECTUAL



Some critical evaluation and analysis of concepts and principles, though descriptive in parts. An emerging awareness the limits of their knowledge and ability to use evidence to support the argument though with some tendency to assert/state opinion rather than argue on the basis of reason and

10

evidence. Mostly valid arguments and logical judgements. (10/20)

4. PRACTICAL APPLICATION



A very good application of a range of established methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive insights. Consistent, accurate and logical application of theory to practice, making appropriate links between the two. Can identify problems and propose appropriate solutions outside the context in which they were first studied. Evidence of some creativity. (12/20)

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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. (16/20)

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