Department of Chemical Engineering

Process Control Lab

ChE-432 Lab Manual

Instructors:

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STUDENT NAME:

STUDENT NUMBER:

SEMESTER / YEAR:

Contents

Section

.1 Introduction

All the experiments given here are performed with the TecQuipment CE2000 software. The Process Trainer is supplied with the CE2000 software and experiment files (see Table 2). The experiment files can be edited and saved as new files by means of the comprehensive tools provided in the CE2000 software. This allows the user to extend the range of experiments.

Please refer to the CE2000 software manual (supplied) for full instructions on how to use the software.

NOTE *Do the experiments in the correct order. The procedures and results from the first experiments are needed to help with the later experiments.*

Experiment	CE2000 File Names
Experiment 1: Basic Control, Hardware and Software Familiarization	Exp1-1.ict
	Exp1-2.ict
	Exp1-3.ict
	Exp1-4.ict
Experiment 2: Basic Proportional Control - Flow Control by Valve	Exp2-1.ict
Experiment 3: Flow Control by Pump	Exp3-1.ict
	Exp3-2.ict
Experiment 4: Level Control of the Process Vessel	Exp4-1.ict
	Exp4-2.ict
	Exp4-3.ict
Experiment 5: Temperature Control of the Heater Tank	Exp5-1.ict
Experiment 6: Temperature and Level Control of the Process Vessel	Exp6-1.ict
Experiment 7: Level Control by Valve Position with Feedforward of Pump Speed	Exp7-1.ict
Experiment 8: Cascade Control of the Process Vessel Level	Exp8-1.ict
Experiment 9: Ratio Control of Process and Heater Loop Flow	Exp9-1.ict
Experiment 10: Pressure Control of the Process Vessel	Exp10-1.ict
	Exp10-2.ict
	Exp10-3.ict

Table 2 CE2000 Experiment Files Supplied with the Process Trainer

2 Connection

For all the experiments, connect the CE117 Mimic Panel to the computer as shown in Section 1 of this guide. Use the leads (supplied) to connect the sockets on the Mimic Panel as shown on the connection diagram for each experiment.

3 Safety

- ***Never use this equipment if you have wet hands or if water has spilled into the electrical circuits.***
- ***Make sure the equipment is dry and safely connected to the electrical supply before you switch it on.***
- ***Do not use this equipment with any of its covers removed.***
- ***Make sure that you are supervised by your lecturer or supervisor whenever you use this equipment.***

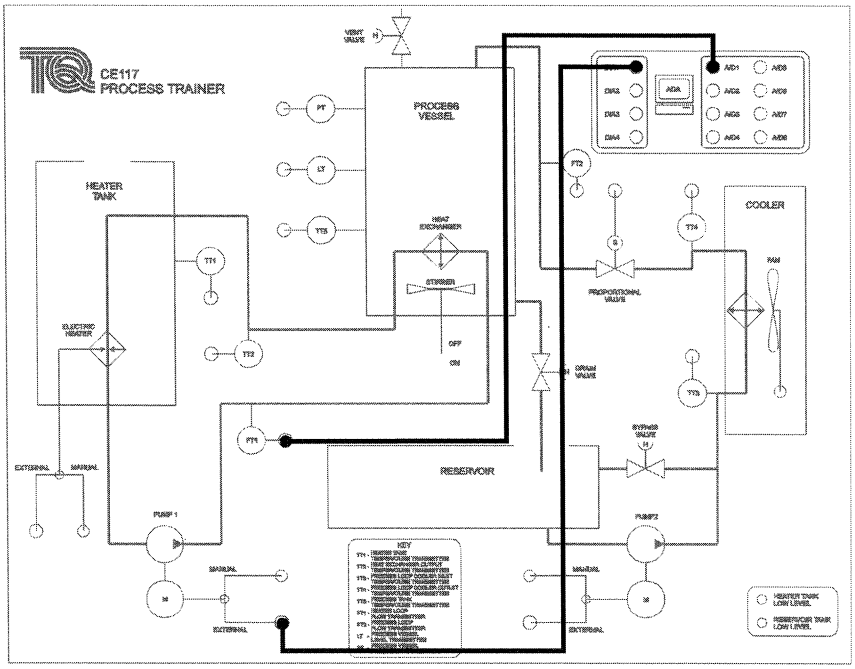

Figure 33 Connections For Experiment 1 Procedure 1

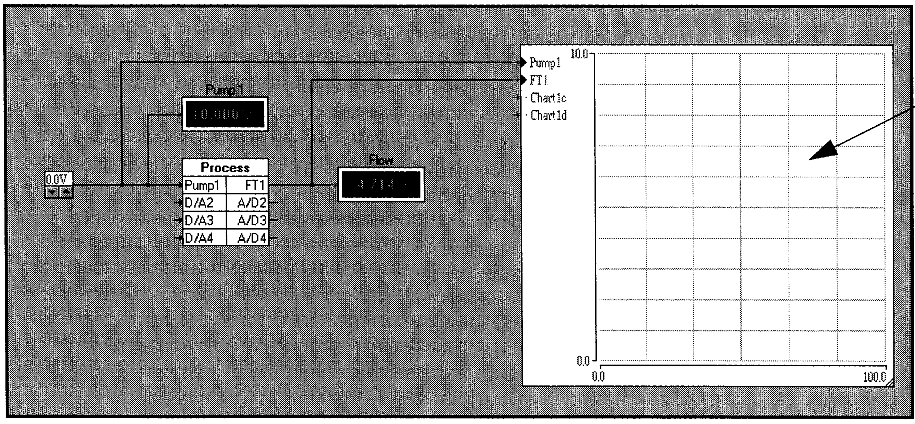

Chart to help you see the pump and flow conditions

Figure 34 Screenshot of Experiment 1 Procedure 1.

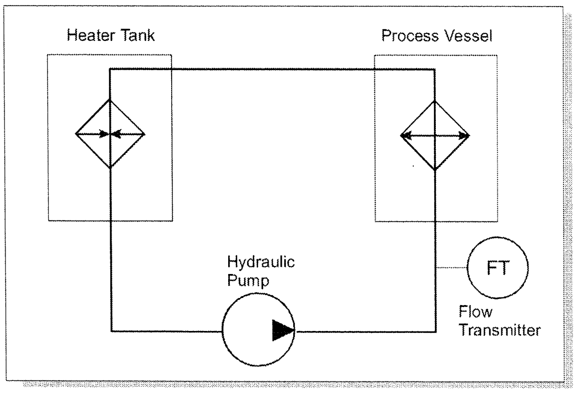

Figure 35 Schematic of Experiment 1 Procedure 1

.4 *Experiment 1: Basic Control, Hardware and Software Familiarization*

Object

To perform basic control and measurement tests to become familiar with the Process Trainer.

Procedure 1 - Heater Loop Pump Characteristic

1) Create a blank results table similar to Table 3.

2) Check that the CE2000 software is installed on your computer. Tell your supervisor if it is not.

3) Start the CE2000 software (double click on the CE2000 icon on your computer desktop). Use the CE2000 software to open the circuit file 'exp1-1.ict' from the default CE2000/CE117 folder (see Figure 36).

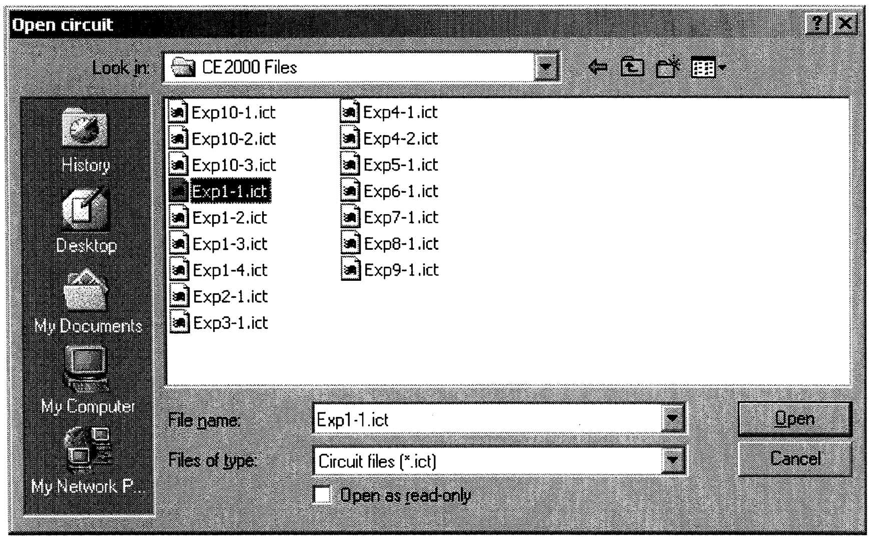

Figure 36 Start the CE2000 Software and Use File - Open - CE2000 - CE117 - exp1-1.ict

4) Connect the CE117 Mimic Panel as shown in Figure 33. Set Pump 1 switch to 'External'. Analogue signals will pass from the ADA section to Pump 1 and from flow transmitter FT1. The software will display and record the flow through the heater loop.

5) You will use the 'Run', 'Record' and 'Stop' buttons on the software. You will also use the chart recorder. Make sure that you are familiar with these items (read the CE2000 Help Files or User Guide).

6) On the software set the Pump voltage to 0 V. Run the software and click on the record button to record the results.

7) In 1 V steps, increase the pump voltage from 0 to 10 V. After each voltage increase, wait for the flow to stabilize, the chart on the software will help to show you this. Use your blank table to record the corresponding flow transmitter voltages.

8) Convert the flow transmitter voltage into flow rate in Litre per minute. Table 1 on page 18 gives details of voltage and flow rate conversions.

9) Draw a block diagram of the control system. Create a graph of Flow (volt) on the vertical axis against Pump (volt) on the horizontal axis. The CE2000 software can do this for you - you must set the

graphing options (see Figure 37), then click on the 'Draw graph' button. (Read the 'Graphing' details in the CE2000 Help Files or User Guide). Your curve is the pump flow characteristic.

10) You may also use the the 'Export Data File' function in the CE2000 software to export your data to other programs to create charts (read the CE2000 Help Files or User Guide).

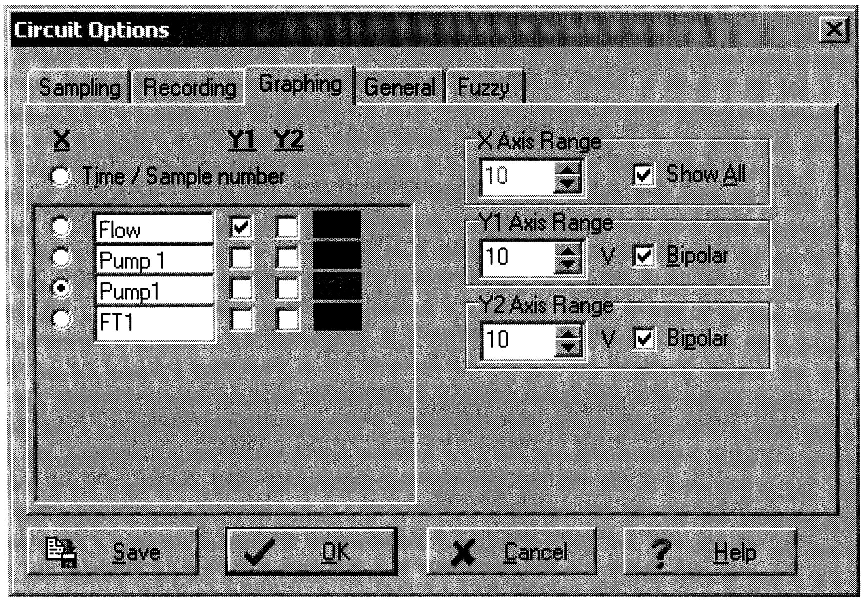

Figure 37 Use the Options - Graphing Dialogue Box to Make the CE2000 Create Your Graph.

Questions

- Is the pump flow characteristic linear?
- At what voltage does the pump start to create a reasonable flow?

Pump (Volt)	Flow Transmitter (Volt)	Flow Rate (Litre/minute)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 3 Blank Results Table

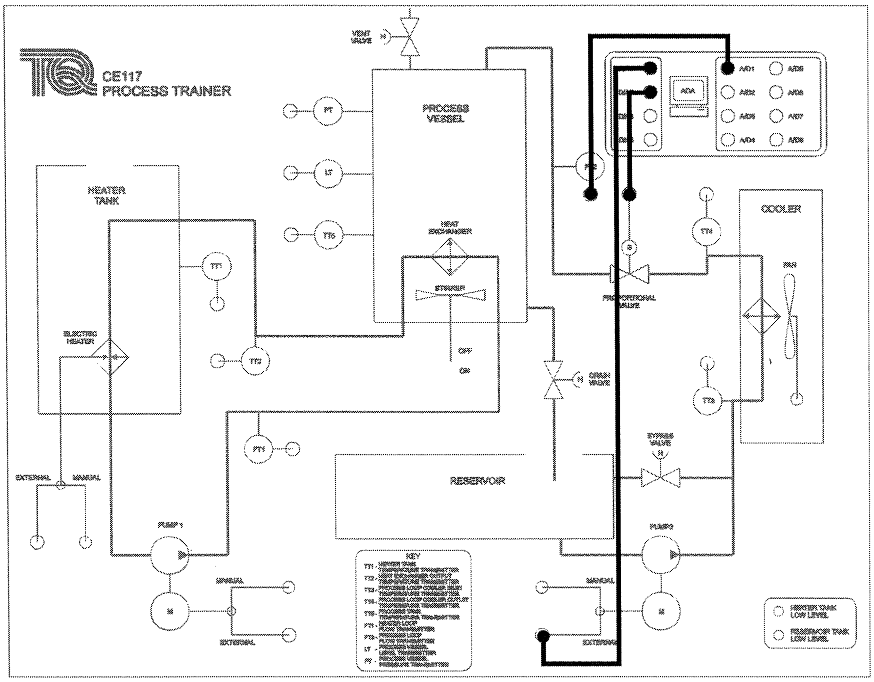

Figure 38 Connections for Experiment 1 Procedure 2.

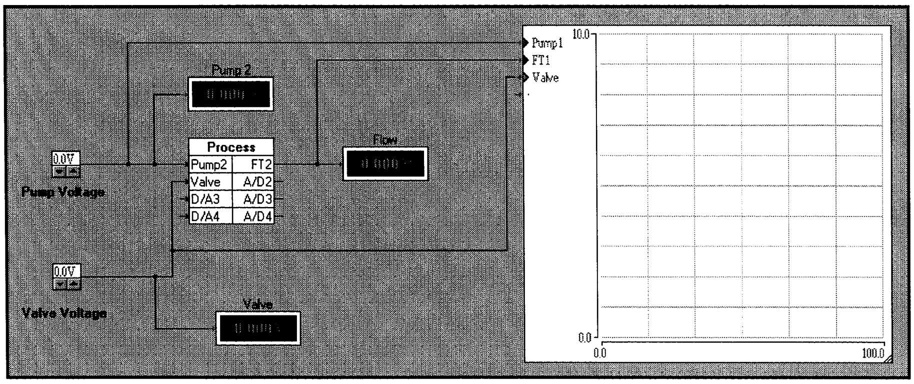

Figure 39 Screenshot of Experiment 1 Procedure 2

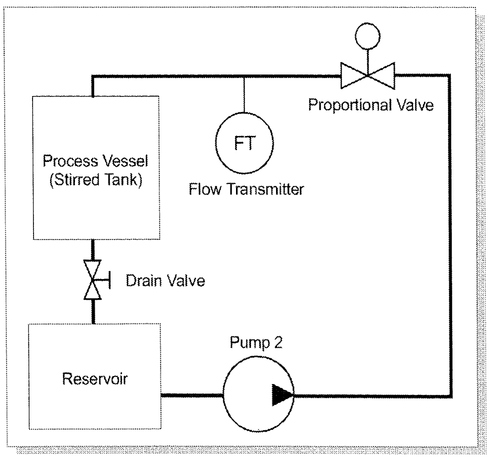

Figure 40 Schematic of Experiment 1 Procedure 2

Procedure 2 - Process Loop Pump and Valve Characteristics

1) Create two blank results tables similar to Table 4 and Table 5.

2) Start the CE2000 software and load file 'exp1-2.ict'.

3) Close the process loop bypass valve, fully open the process vessel drain valve and open the air vent valve.

4) Connect the CE117 Mimic Panel as shown in Figure 38. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve S and from flow transmitter FT2. The software will display the flow through the process loop.

Pump Characteristic

5) On the software, set the **pump** voltage to 0 V and apply a full 10 V to the **valve** (fully open). Run the software. In 1 V steps, increase the **pump** voltage from 0 to 10 V. After each voltage increase, wait for the flow to stabilize, the chart will help. Use your blank table to record the corresponding flow transmitter voltages. You may also use the record button on the software to record your readings.

6) Convert the flow transmitter voltage into flow rate in Litre per minute. Table 1 on page 18 gives details of voltage and flow rate conversions.

7) Draw a block diagram of the control system. Create a chart of Flow (volt) on the vertical axis against **Pump** (volt) on the horizontal axis. You may use the CE2000 software to do this for you. Your curve is the **pump** flow characteristic.

Valve Characteristic

8) On the software, set the **valve** voltage to 0 V and apply a full 10 V to the **pump** (full flow). Run the software. In 1 V steps, increase the **valve** voltage from 0 to 10 V. After each voltage increase, wait for the flow to stabilize, the chart will help. Use your blank table to record the corresponding flow transmitter voltages. You may also use the record button on the software to record your readings.

9) Convert the flow transmitter voltage into flow rate in Litre per minute. Table 1 on page 18 gives details of voltage and flow rate conversions.

10) Draw a block diagram of the control system. Create a chart of Flow (volt) on the vertical axis against **Valve** (volt) on the horizontal axis. You may use the CE2000 software to do this for you. Your curve is the **valve** characteristic.

Questions

- Is the pump flow characteristic linear?
- At what voltage does the pump start to create a reasonable flow?
- Is the valve characteristic linear?
- At what voltage does the valve allow a reasonable flow?

Pump (Volt)	Flow Transmitter (Volt)	Flow Rate (Litre/minute)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 4 Blank Results Table for Pump Flow Characteristics

Valve (Volt)	Flow Transmitter (Volt)	Flow Rate (Litre/minute)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Table 5 Blank Results Table for Valve Characteristics

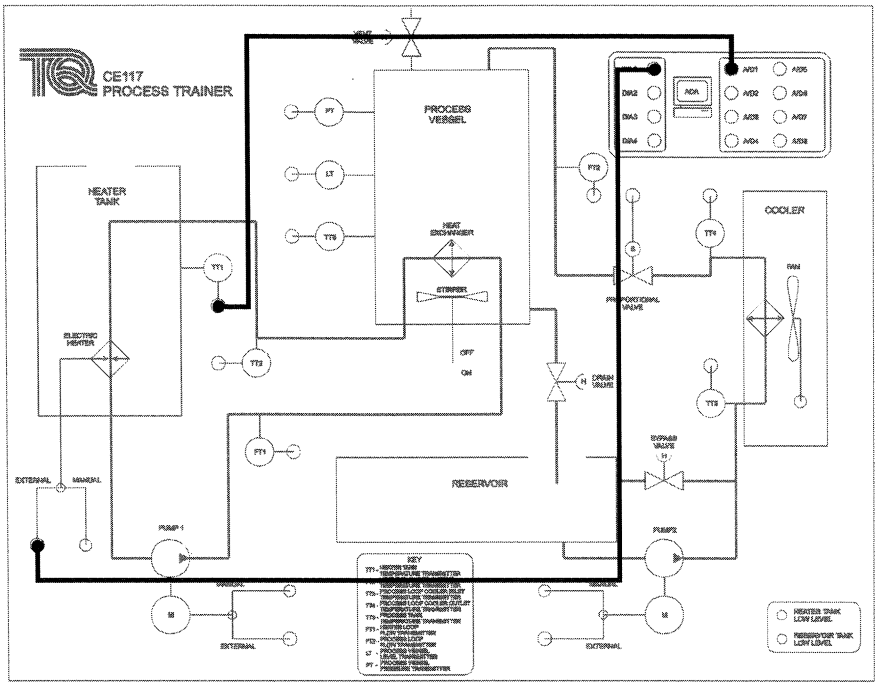

Figure 41 Connections for Experiment 1 Procedure 3.

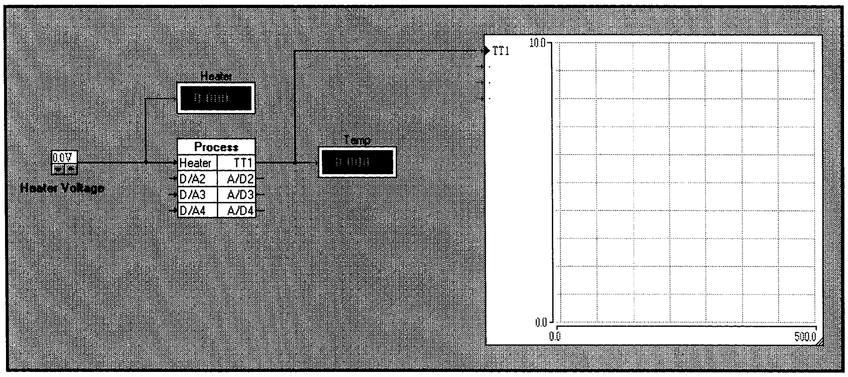

Figure 42 Screenshot of Experiment 1 Procedure 3

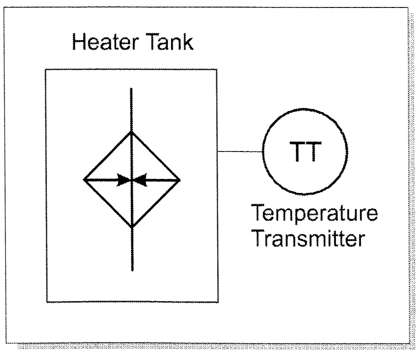

Figure 43 Schematic of Experiment 1 Procedure 3

Procedure 3 - Heater Control

1) Start the CE2000 software and load file 'exp1-3.ict'.

2) Connect the CE117 Mimic Panel as shown in Figure 41. Set the heater switch to 'External'. Analogue signals will pass from the ADA section to the heater and from temperature transmitter TT1. The software will display the temperature rise in the heater tank.

3) Run the software and apply a full 10 V to the heater (full power).

4) Note how quickly the heater tank reaches the maximum temperature of approximately 60°C. The chart on the software will show the temperature rise against time.

5) Turn the heater voltage down to 0 V (power off).

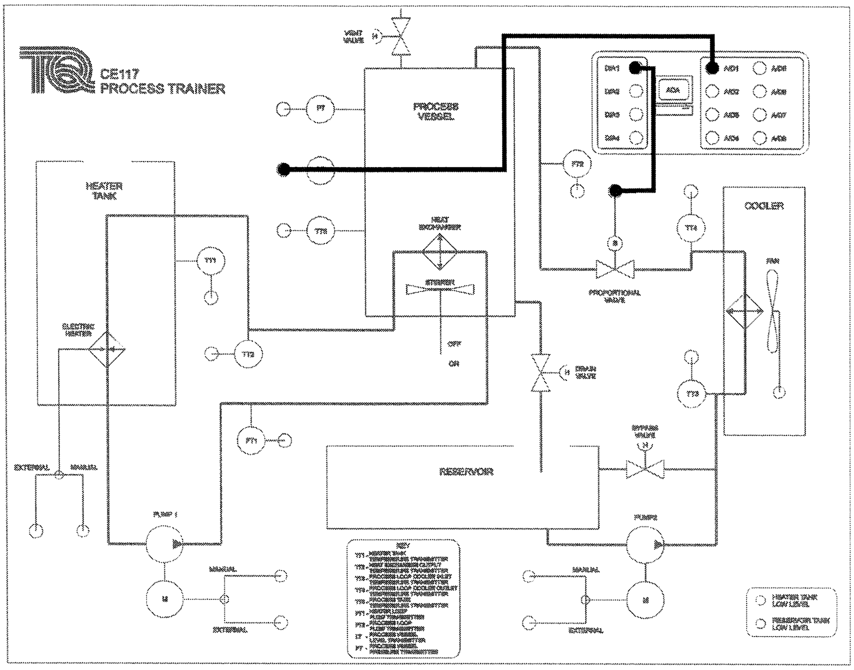

Figure 44 Connections for Experiment 1 Procedure 4

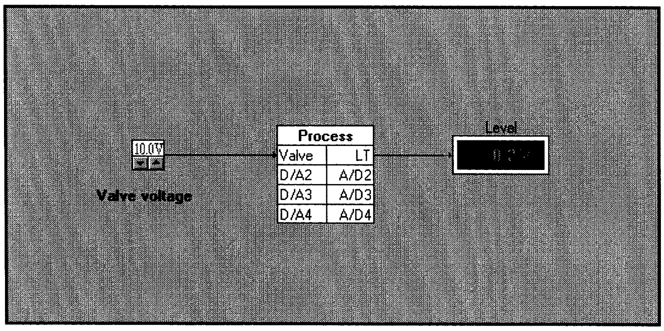

Figure 45 Screenshot of Experiment 1 Procedure 4

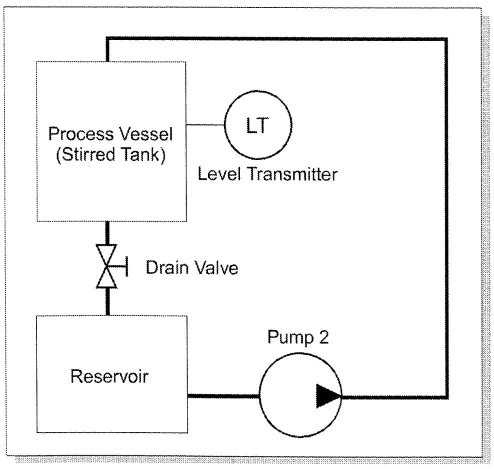

Figure 46 Schematic of Experiment 1 Procedure 4

Procedure 4 - Level Transducer Characteristic and Calibration

1) Create a blank results table similar to Table 6.

2) Start the CE2000 software and load file 'exp1-4.ict'. Make sure that the reservoir water level is correct.

3) Connect the CE117 Mimic Panel as shown in Figure 44. Analogue signals will pass from the ADA section to the valve and from level transmitter LT. The software will display the level rise in the process vessel.

4) Switch Pump 2 to 'Manual' control and set its control to minimum. Run the software and apply a full 10 V to the valve (fully open). Close the process loop bypass valve and the process vessel drain valve. Open the air vent valve.

5) Use the manual control of Pump 2 to slowly increase the level in the process vessel. At each 10 mm step, record the level transmitter reading (in volt). The reservoir slowly empties, so as the process vessel level reaches a level of around 180 mm, the reservoir low water level switch will operate and stop the pump.

6) Plot a chart of Level Transmitter Output on the vertical axis against the water level of the process vessel on the horizontal axis. Your curve is the characteristic of the level transmitter.

Note: The level tranducer is calibrated by TecQuipment to give outputs of 10 V and 0 V (+/- 0.05 V) at the 180 mm and 0 mm levels on the process vessel. If it does not, your lecturer must re-calibrate the transducer.

Question

- Is the Level Transmitter characteristic linear?

Water Level inside the Process Vessel (mm)	Level Transmitter Output (V)
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	
130	
140	
150	
160	
170	
180	
190	
200	

Table 6 Blank Results Table for Experiment 1 Procedure 4

Procedure 5 - To Edit and Build Your Own Circuits

The procedures, connection diagrams and CE2000 software circuits (*.ict files) in this guide are all suggested by TecQuipment to help you to learn with the CE117. You can also extend the experiments by the addition of your own ideas.

You may:

- Edit the existing connections and circuits and save them (with a new name).
- Create new connection diagrams and circuits.

There is a blank connection diagram at the back of this guide for you to copy and use to draw your own diagrams.

To edit an existing circuit:

1) Use your computer operating system to create a new folder for your work.

2) Start the CE2000 software and use it to open the circuit that you need to edit (for example: exp 8-1.ict).

3) Save the circuit in your new folder, and use a new name for the circuit file (for example: My_exp-1.ict).

4) Use the tools in the CE2000 software to edit the circuit. Refer to the CE2000 guide for details.

To build your own circuit:

1) Decide what parts of the CE117 are to be connected (for example: pumps, transducers and the valve).

   Draw a connection diagram, so that your output devices (for example: pumps and valve) are connected to the red (D/A) sockets of the Mimic Panel, and your input devices (transducers) are connected to the black (A/D) sockets of the Mimic Panel. Copy and use the blank connection diagram at the back of this guide.
   Figure 47 shows an example of a circuit that will control the valve and Pump 2, and monitor the level in the Process Vessel

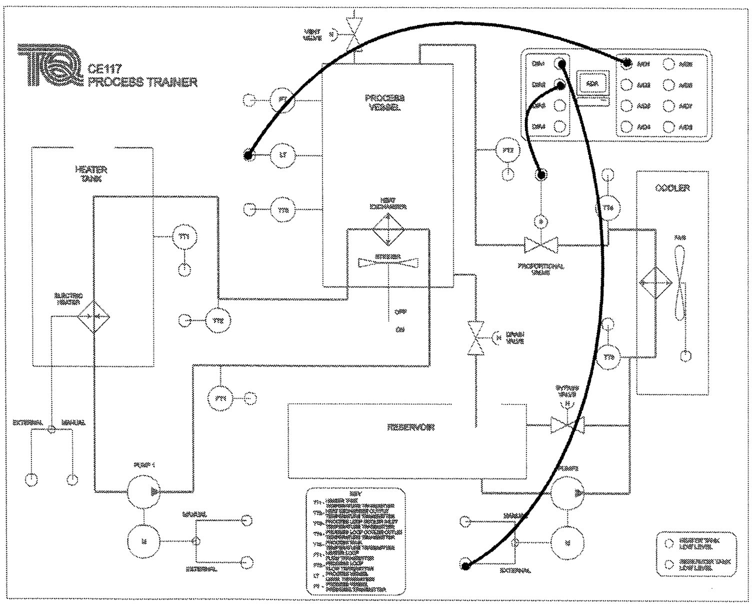

Figure 47 An Example of a Connection Diagram Drawing

2) Start the CE2000 software. It will open with a blank circuit page that contains a Process Block (see Figure 48).

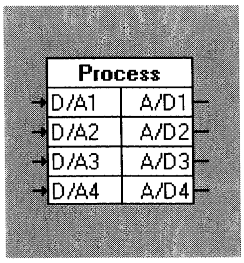

Figure 48 The Process Block

3) The default Process Block has four D to A channels (D/A1 to D/A4) and four A to D channels (A/D1 to A/D4). This block is basically a mirror copy of the ADA section of the CE117 Mimic Panel. Four A/D channels are usually enough for most experiments, but you may add extra channels to a maximum of eight, to match those on the CE117 Mimic Panel. Refer to the CE2000 manual for details.

Note *The process signals* ***leave*** *the Process Block from the A/D channels and* ***enter*** *the Process Block by means of the D/A channels. On the CE117 Mimic Panel, it is the opposite (see Figure 49).*

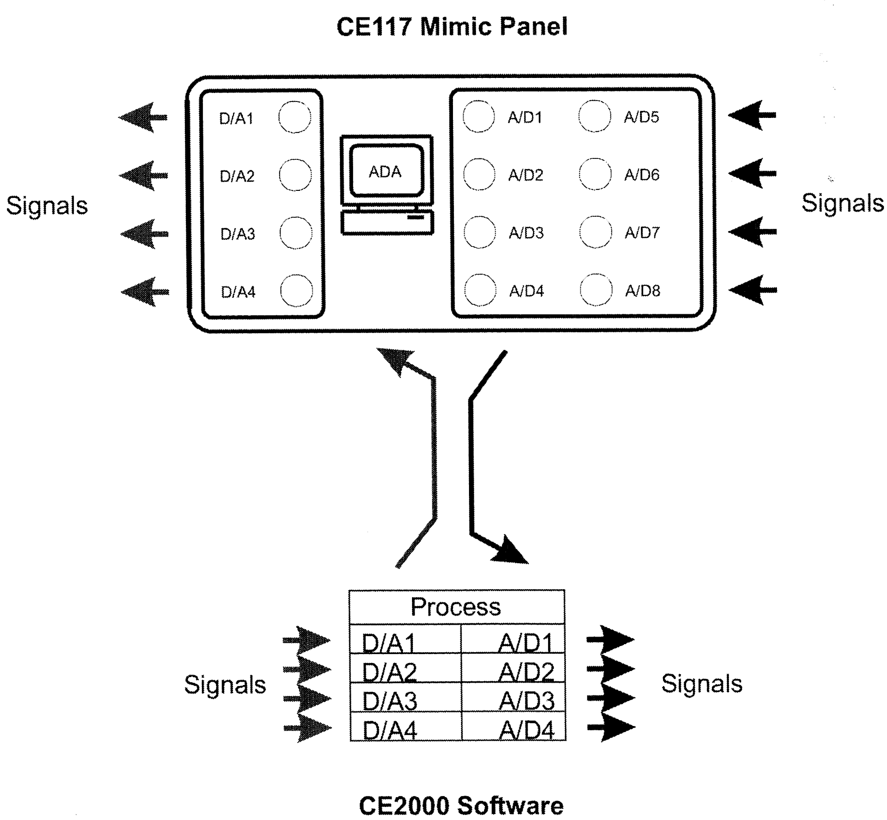

Figure 49 Signals In and Out of the ADA Section and the CE2000 Process Block

4) Use the tools of the CE2000 software to connect the channels of the Process Block to other blocks of the software. Figure 50 shows an example of two DC voltage level blocks connected to channels D/A1 and D/A2. A digital volt meter block is connected to channel A/D1.

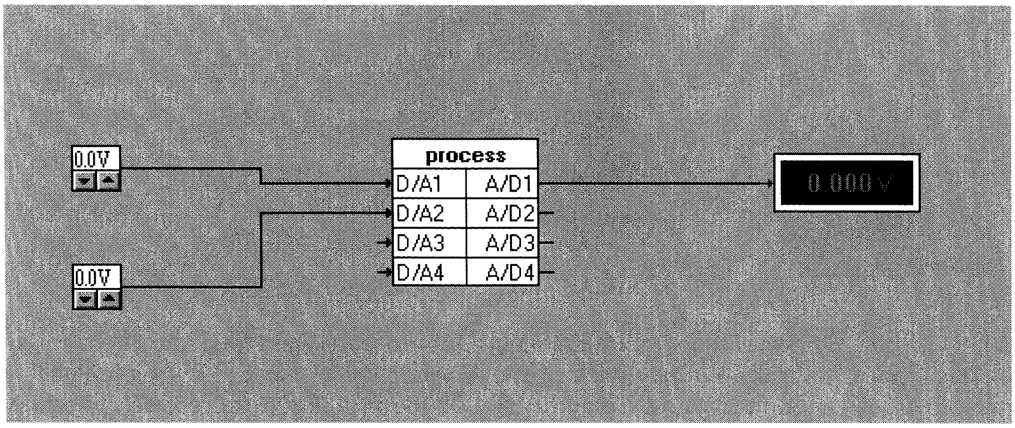

Figure 50 Process Block Channels Connected

5) Rename the inputs and outputs of the Process Block to match the connections of your Mimic Panel. In this example, channel D/A1 of the Mimic Panel is connected to Pump 2, D/A2 is connected to the valve and A/D1 is connected to the Level Transducer. See Figure 51.

6) Switch on the CE117 Hardware and make sure that the Mimic Panel is connected to your computer.

7) If you are to use a pump or heater, make sure that its Manual/External switch is set to external.

8) Run the software and check that it works as you expect. For this example, Pump 2 speed and the valve opening will increase as you increase the DC levels. If you close the Process Vessel drain valve, the Level transducer output will start to increase as the water in the vessel rises.

9) Save your new circuit.

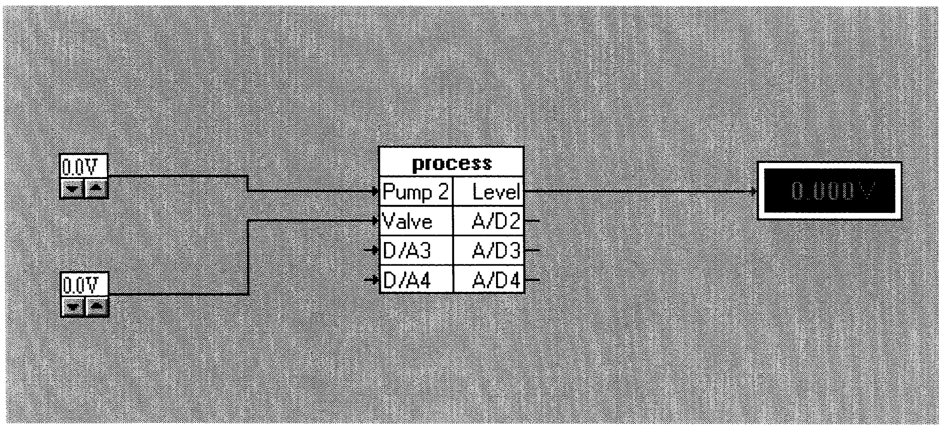

Figure 51 Process Block Renamed

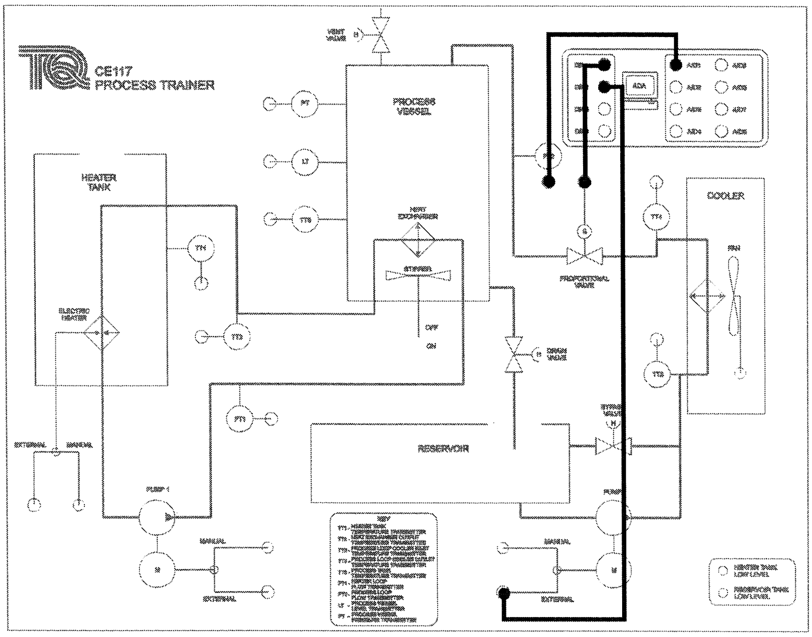

Figure 52 Connections for Experiment 2 Procedure 1

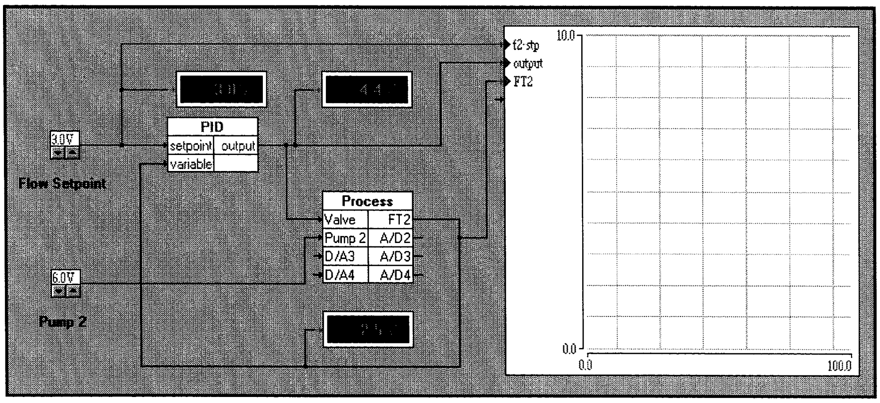

Figure 53 Screenshot of Experiment 2 Procedure 1

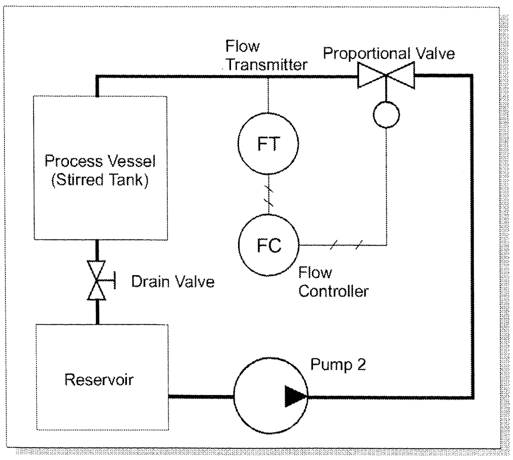

Figure 54 Schematic of Experiment 2 Procedure 1

5 Experiment 2: Basic Proportional Control - Flow Control by Valve

Object

To investigate the use of the proportional valve position to control flow rate in the process loop.

Procedure

1) Start the CE2000 software and load file 'exp2-1.ict'.

2) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

3) Connect the CE117 Mimic Panel as shown in Figure 52. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve S and from flow transmitter FT2.

4) On the software, the block titled 'PID' is a three term controller that controls the valve voltage. You may adjust the controller's values of Proportional gain, Integral and Derivative. Set the PID controller to:

   Proportional gain - 0.5
   Integral - 0.5
   Derivative - 0 (zero)

5) Run the software and use it to record the flow response. Adjust the flow setpoint to 0.5 V and Pump 2 voltage to 6 V and wait for the flow to stabilize.

6) Increase the flow setpoint in steps of 0.5 V up to a maximum of 3 V. At each step change, allow the flow to stabilize (should take less than 20 seconds). Adjust the flow setpoint back to 0.5 V and wait for the flow to stabilize (should take less than 20 seconds). You may use the software to record and create a chart of the results.

NOTE *This experiment does not control level, so at setpoints above 2 V the reservoir can run low and switch off the pump. To avoid this, perform this part of the experiment as quickly as possible.*

7) Increase the flow setpoint to 2 V and wait a few seconds for the flow to stabilize.

8) Part-open the process loop bypass valve to reduce the loop flow. Close the bypass valve, wait for the flow to stabilize. Reduce the pump voltage by 2 V to reduce the flow.

9) Draw a block diagram of the control system.

Questions

- How well does the system respond to changes in setpoint?
- How well does the system respond to disturbances?

Extra Experiment

If you have read and understood the CE2000 User Guide or are familiar with PID control, repeat the experiment with different values of the proportional and integral terms. What do you notice about the system response for a change in each of these terms? Why do you think the derivative term is set to 0 in this system?

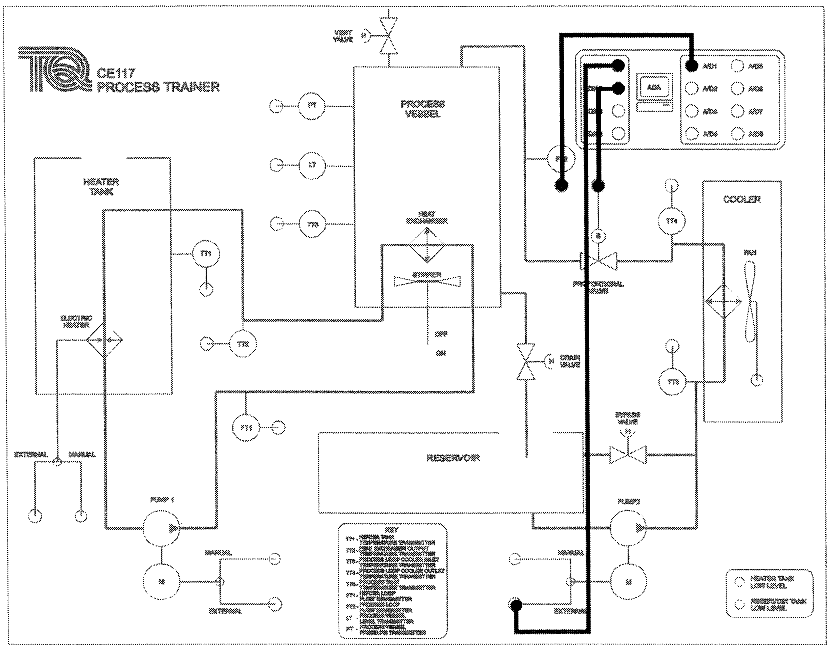

Figure 55 Connections for Experiment 3 Procedure 1

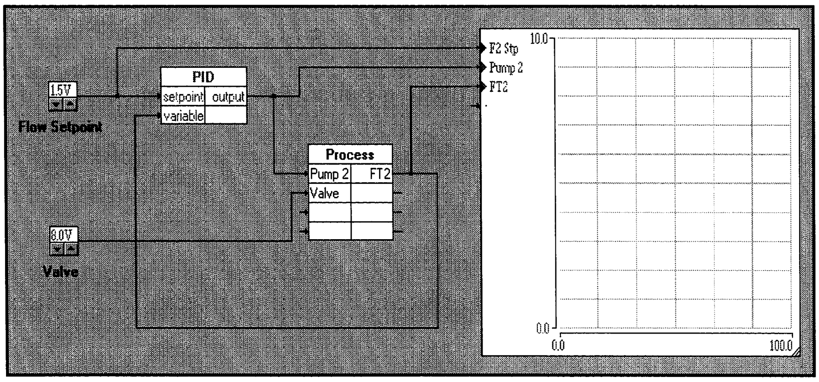

Figure 56 Screenshot of Experiment 3 Procedure 1

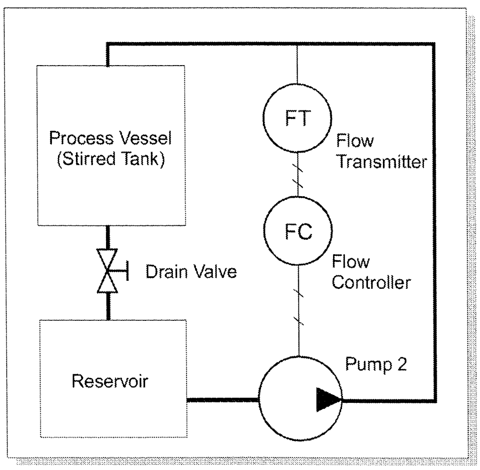

Figure 57 Schematic of Experiment 3 Procedure 1

6 *Experiment 3: Flow Control by Pump*

Objects

- To investigate the use of the pump speed for control of flow rate in the process loop.
- To demonstrate the effect of derivative action and the importance of the 'washout' filter.

Procedure 1 - Flow Control with Proportional and Integral Action

1) Start the CE2000 software and load file 'exp3-1.ict'.

2) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

3) Connect the CE117 Mimic Panel as shown in Figure 55. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve (S) and from flow transmitter (FT2).

4) On the software, the block titled 'PID' is a three term controller that controls the pump voltage. You may adjust the controller's values of Proportional gain, Integral and Derivative. Set the PID controller to:

   Proportional gain - 0.5
   Integral - 0.5
   Derivative - 0 (zero)

5) Run the software and use it to record the flow response. Adjust the Setpoint to 1 V and the valve voltage to 8 V and wait for the flow to stabilize.

6) Increase the flow setpoint in steps of 0.5 V up to a maximum of 3 V. At each step change, allow the flow to stabilize (should take less than 30 seconds). Adjust the flow setpoint back to 1 V and wait for the flow to stabilize (should take less than 30 seconds). You may use the software to record and create a chart of the results.

NOTE *This experiment does not control level, so at setpoints above 2 V the reservoir can run low and switch off the pump. To avoid this, perform this part of the experiment as quickly as possible.*

7) Increase the flow setpoint to 2 V and wait a few seconds for the flow to stabilize.

8) Part-open the process loop bypass valve to reduce the loop flow. Close the bypass valve, wait for the flow to stabilize. Reduce the valve voltage by 2 V to reduce the flow.

9) Draw a block diagram of the control system.

Questions

- How well does the system respond to changes in setpoint?
- How well does the system respond to disturbances?

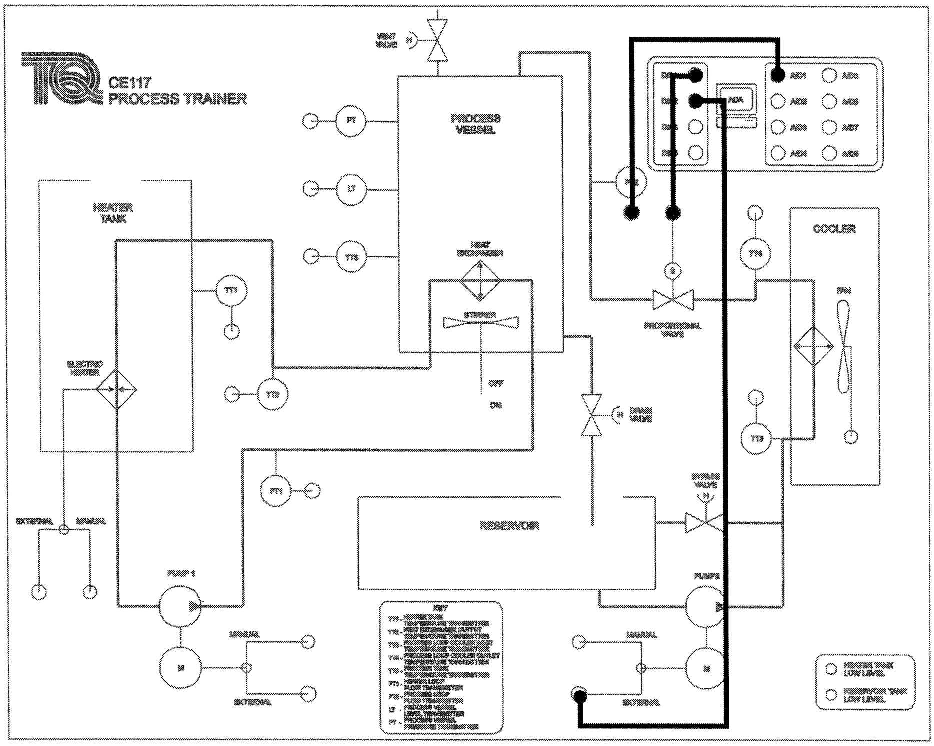

Figure 58 Connections for Experiment 3 Procedure 2

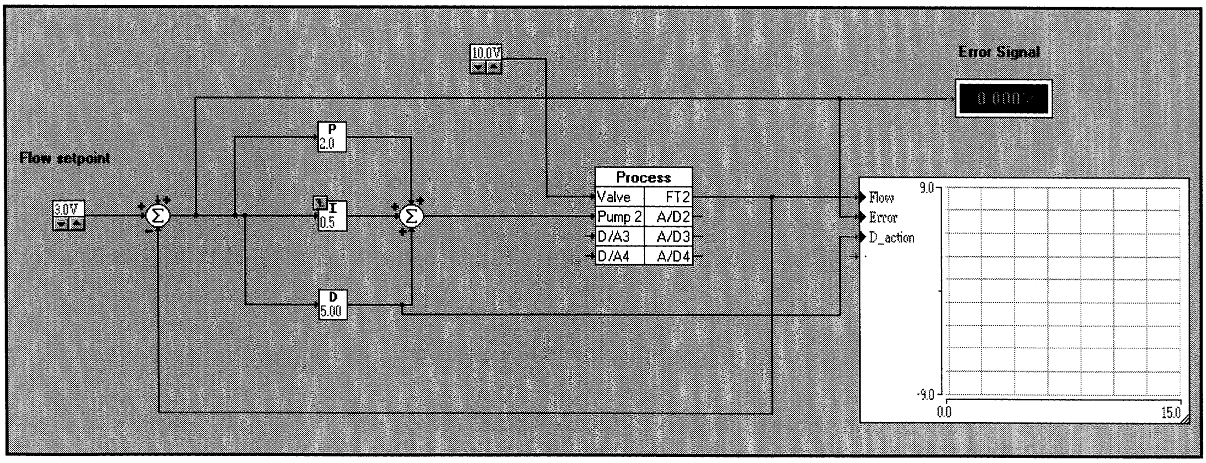

Figure 59 Screenshot of Experiment 3 Procedure 2

Procedure 2 - Demonstration of Derivative Action

1) Start the CE2000 software and load file 'exp3-2.ict'.

2) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

3) Connect the CE117 Mimic Panel as shown in Figure 58. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve (S) and from flow transmitter (FT2).

4) On the software, a three term controller is made from three individual (P, I and D) blocks that control the pump voltage. Set the blocks to:

   Proportional gain - 2
   Integral - 0.5
   Derivative - 0 (zero)

5) Run the software and use it to record the flow response, the error and the derivative action (D_action). Adjust the Setpoint to 3 V and the valve voltage to 10 V (fully open) and wait for the flow to stabilize.

6) Increase the flow setpoint by 1 V. Note that the output from the derivative block (D_action) does not change. Decrease the setpoint by 1 V and again note that there is no output from the D block.

7) Stop the software and change the D block gain to 5 and its Washout gain to 5. Make sure that the Washout 'Enabled' check box is ticked. Run the software and allow it to stabilize.

8) Increase the flow setpoint by 1 V. Note the output from the derivative block (D_action). Decrease the setpoint by 1 V and again note the D block output (D_action).

9) Stop the software and make sure that the Washout 'Enabled' check box is ***not*** ticked. Run the software and allow it to stabilize. Repeat step 8.

10) While the software runs, enable and disable the washout filter.

Questions

- What do you notice about the output of the D block and its effect on the pump speed?
- What do you notice about the effect of the Washout Filter?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

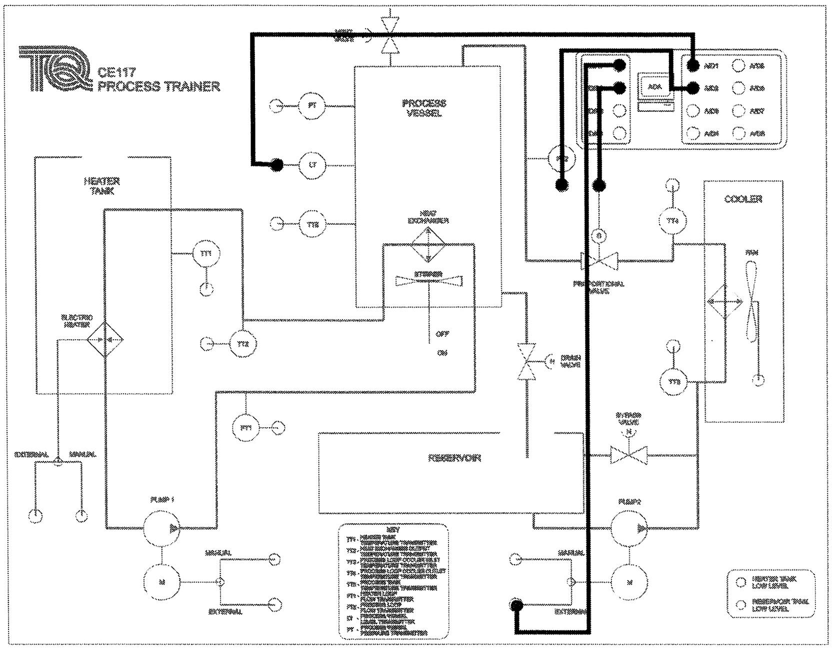

Figure 60 Connections for Experiment 4 Procedure 1

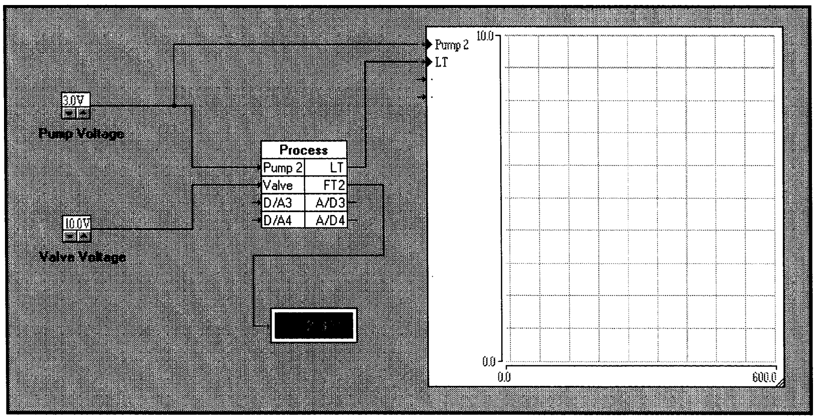

Figure 61 Screenshot of Experiment 4 Procedure 1

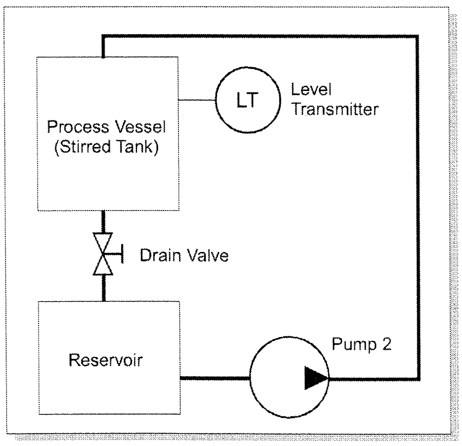

Figure 62 Schematic of Experiment 4 Procedure 1

7 *Experiment 4: Level Control of the Process Vessel*

Objects

- To control the level in the process vessel and to measure its time constant.
- To demonstrate the use of ON/OFF control of level

Procedure 1 - Open Loop Level Step Response Test

1) Start the CE2000 software and load file 'exp4-1.ict'.

2) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

3) Connect the CE117 Mimic Panel as shown in Figure 60. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve S and from level transmitter LT.

NOTE *The connection to the flow transmitter is for reference only.*

4) On the software, set Pump 2 voltage to 4 V and the Valve to 10 V (fully open). Run the software and use it to record the level.

5) Carefully adjust the pump voltage until the level stabilizes just above the top of the heat exchanger. When you have done this, wait for at least ten minutes to ensure that the level remains stable. Make a note of the height of the water in the process vessel and the flow rate. This is Level A.

6) Increase the pump voltage by 0.5 V. Monitor the level until it becomes stable, this should take less than 15 minutes. Make a note of the height of the water in the process vessel and the flow rate. This is Level B.

7) Stop the CE2000 software running. Use its graph features to plot the level and pump input against time (time response curve).

8) Switch off the apparatus.

9) Draw a block diagram of the system.

10) From your plot, estimate the time constant (approximately 62.3% of the time to reach Level B) for the process vessel. You may use the time constant function of the CE2000 graph software to do this for you.

11) To double check your results, <u>calculate</u> the time constant of the process vessel. To do this:

   a) Calculate the area (A) of the process vessel.
   Note: The internal diameter of the process vessel is 150 mm.

   b) Convert the steady state levels in the process vessel (h) into metres.

   c) Convert the flow rates (q) to m^3/second (1 Litre = 0.001 m^3). Refer to Table 1 on page 18 of this guide for the voltage to flow conversion of the flow transmitter.

   d) Calculate the outflow resistance (R) from:

$$R = \frac{\Delta h}{\Delta q}$$

e) Calculate the time constant (τ) in seconds from:

$$\tau = AR$$

10) Repeat the calculation for each steady state level. Compare the measured and calculated time constants.

	Flow rate (Volt)	Flow rate (L/minute)	Flow rate q (m^3/sec)	h (m)
Level A				
Level B				
		Difference		
Area $A = \pi \times r^2 =$ _______ m^2				
$R = \Delta h / \Delta q =$ _______				
$\tau = A \times R =$ _______ s				

Table 7 Blank Results For Experiment 4 Procedure 1

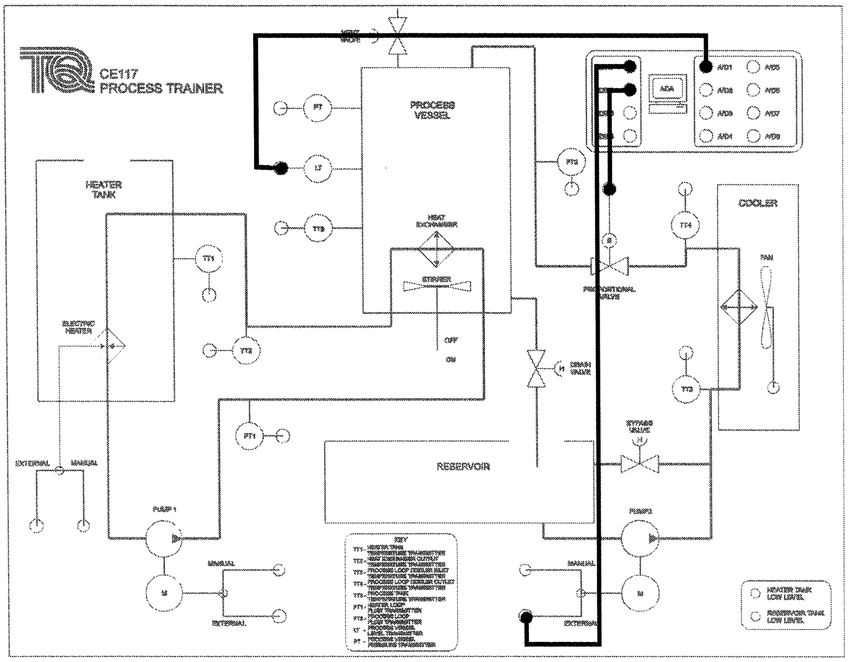

Figure 63 Connections For Experiment 4 Procedure 2

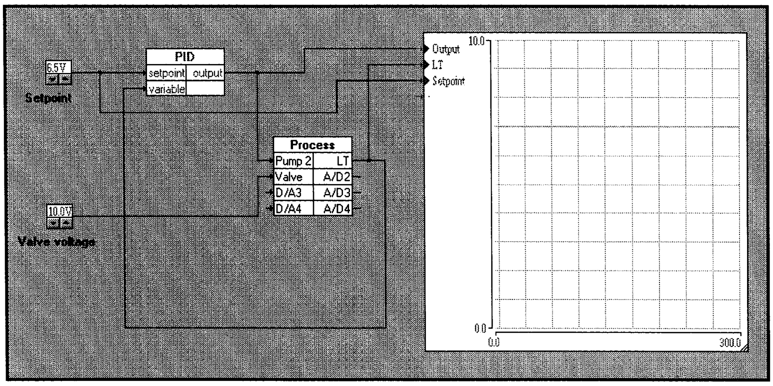

Figure 64 Screenshot of Experiment 4 Procedure 2

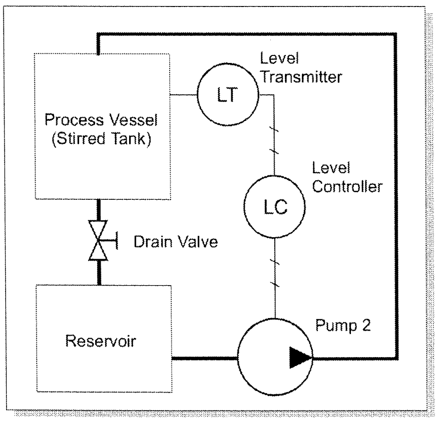

Figure 65 Schematic of Experiment 4 Procedure 2

Procedure 2 - Level Control by Pump Speed

1) Start the CE2000 software and load file 'exp4-2.ict'.

2) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

3) Connect the CE117 Mimic Panel as shown in Figure 63. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve (S) and from level transmitter (LT).

4) On the software, the block titled 'PID' is a three term controller that controls the pump voltage. You may adjust the controller's values of Proportional gain, Integral and Derivative. Set the PID controller to:

   Proportional gain - 10
   Integral - 0.5
   Derivative - 0 (zero)

5) Run the software. Adjust the Setpoint to 6 V and the valve voltage to 10 V (fully open) and wait for the level to stabilize.

6) Increase the setpoint by 0.5 V and use the software to monitor the level until it becomes stable. Compare the response with the open loop test of Procedure 1.

7) Reduce the setpoint back to 6 V and let the system stabilize. Repeat the procedure with PID values:

A (Gain Only)	B (Integral Only)
Proportional gain - 20	Proportional gain - 5
Integral - 0	Integral - 0.5
Derivative - 0 (zero)	Derivative - 0 (zero)

8) Note how well the system responds.

9) Draw a block diagram of the system.

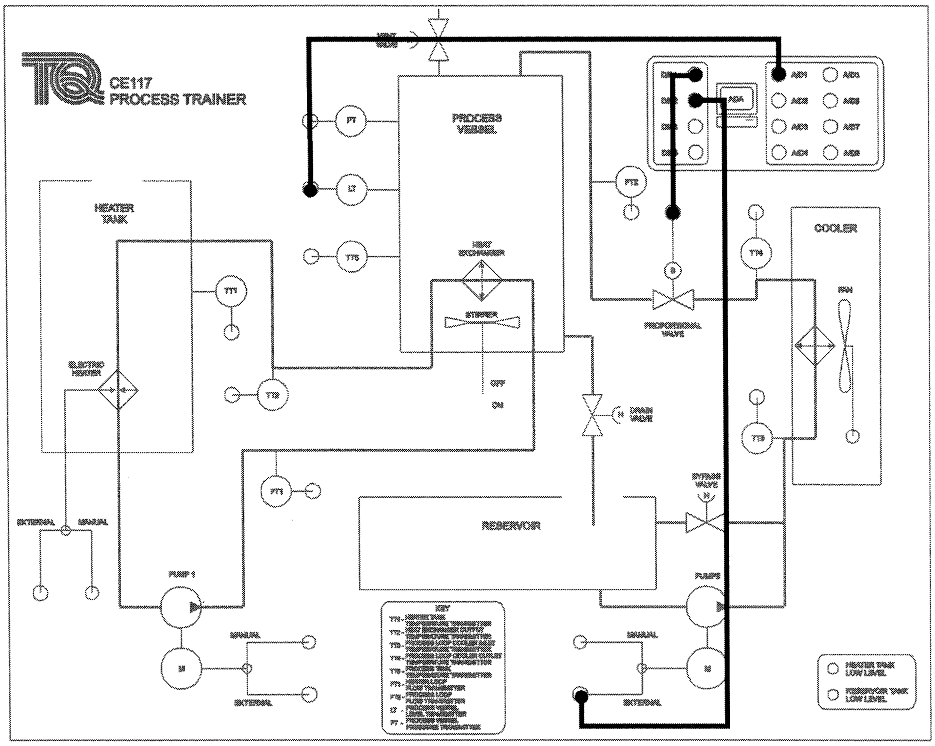

Figure 66 Connections For Experiment 4 Procedure 3

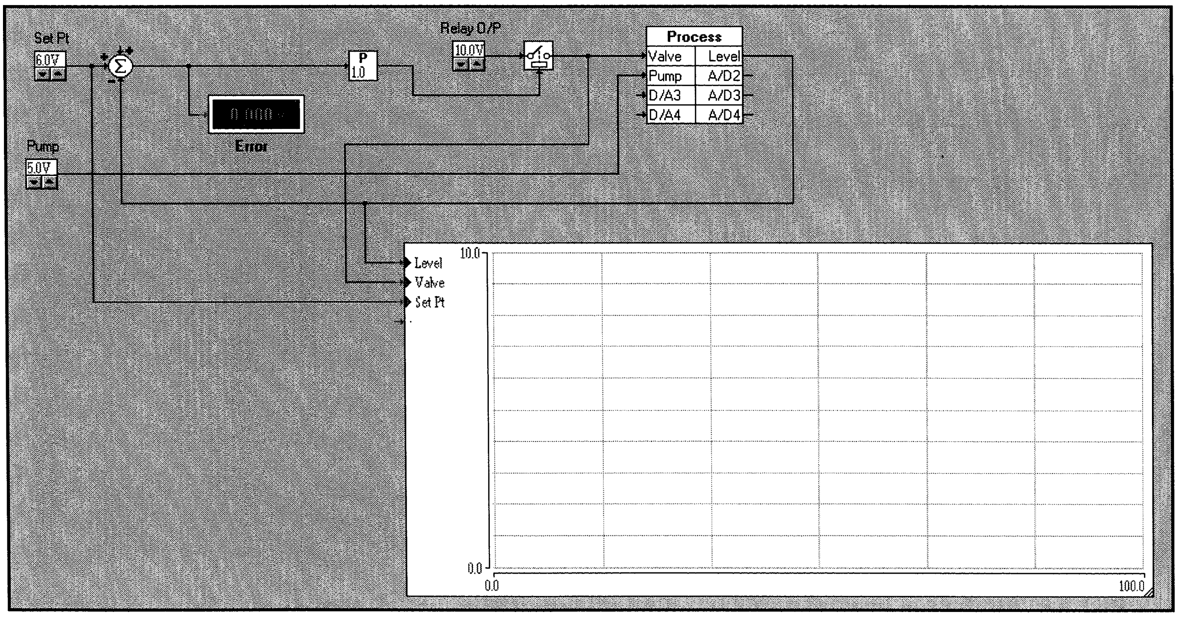

Figure 67 Screenshot of Experiment 4 Procedure 3

Procedure 3 - ON/OFF Control of Level

1) Start the CE2000 software and load file 'exp4-3.ict'.

2) Close the loop bypass valve, fully open the air vent and open the process vessel drain valve to approximately 45°.

3) Connect the CE117 Mimic Panel as shown in Figure 66. Set Pump 2 switch to 'External'. Analogue signals will pass from the ADA section to Pump 2, the proportional valve (S) and from level transmitter (LT). The relay block in the software turns the proportional valve fully on and fully off, so that it acts like a standard solenoid valve.

4) On the software, the 'P' block is a simple gain device for the relay control voltage. Set the blocks to:

   Proportional gain 1
   Pump Voltage to 5 V
   Setpoint to 6 V
   Set the relay to 'Switch on at' 0.5 V with a Hysteresis of 1 V

5) Run the software. Wait for the level to stabilize into a simple oscillation. Use the software to record the level, the valve voltage and the setpoint over at least two cycles.

6) Click on the P (gain) block and change the gain to 2. Again, wait for the level to stabilize into a simple oscillation. Again, use the software to record the results over at least two cycles.

7) Repeat with the gain set to 4.

Questions

- Comment on the action of the ON/OFF control.
- What do you notice about the magnitude of the variation in the level - above and below the setpoint?
- What effect does the change in P (gain) have on:

a) the magnitude of the level variation

b) the ratio of the ON/OFF time

c) the period of the cycle

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

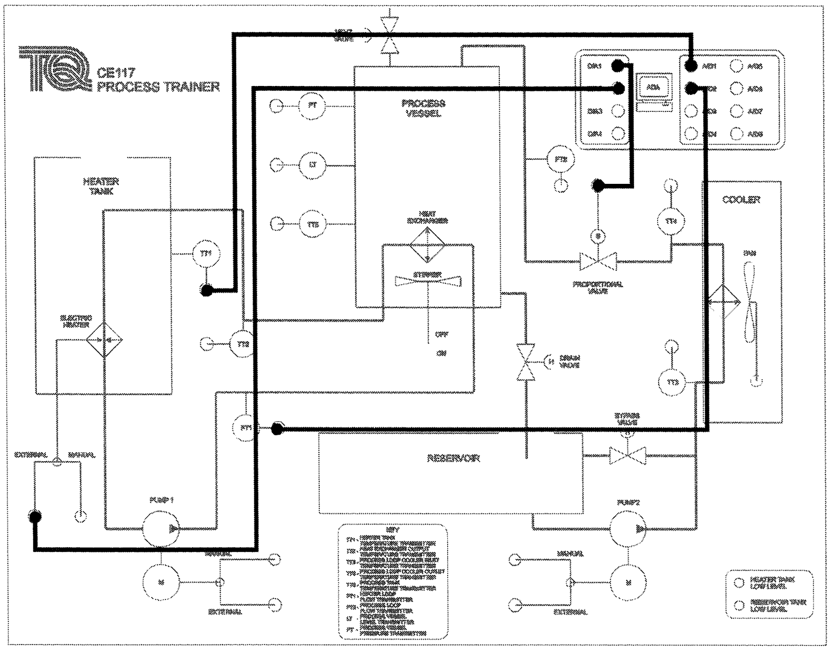

Figure 68 Connections for Experiment 5

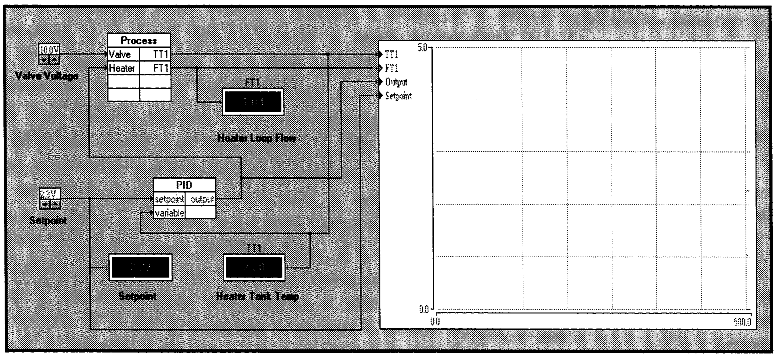

Figure 69 Screenshot of Experiment 5

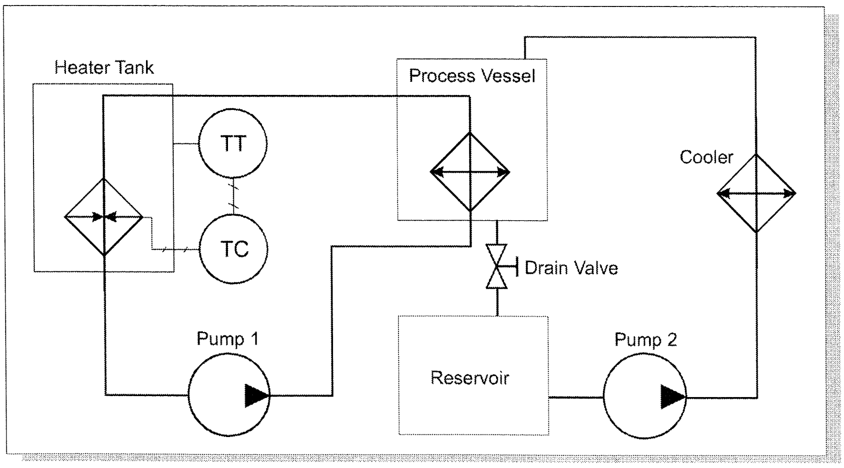

Figure 70 Schematic of Experiment 5

8 Experiment 5: Temperature Control of the Heater Tank

Object

To control the temperature in the heater tank by adjustment of the heater power.

Procedure

NOTE

- *Ambient temperature changes will affect this experiment. Do this experiment in a temperature stable environment, or at a time of day when the temperature remains constant.*
- *This experiment may take up to two hours to perform.*

1) Start the CE2000 software and load file 'exp5-1.ict'.

2) Connect the CE117 Mimic Panel as shown in Figure 68. Analogue signals will pass to the ADA section from the temperature transmitter TT1. The software will instruct the ADA section to pass 10 V to the proportional valve to keep it fully open. The software will display the temperature in the heater tank and the flow in the heater loop.

3) On the software, the block titled 'PID' is a three term controller that controls the heater voltage. You may adjust the controller's values of Proportional gain, Integral and Derivative. Set the PID controller to:

   Proportional gain - 1
   Integral - 0.01
   Derivative - 0 (zero)

4) Close the loop bypass valve, fully open the process vessel drain valve and the air vent.

5) On the Mimic Panel, set the heater switch to 'Manual' and turn the control down to minimum (heater off). Set Pump 1 and Pump 2 switches to 'Manual'. Turn Pump 1 control to minimum, turn Pump 2 control to maximum. Switch on the process vessel stirrer and set the cooler fan to maximum speed.

6) Run the software.

7) On the Mimic Panel carefully adjust Pump 1 to give a low heater loop flow of approximately 1 L/min and allow the system to stabilize. Refer to Table 1 on page 18 of this guide for the voltage to flow conversion of the flow transmitters.

8) Wait until the temperature of the water in the heater tank stabilizes to an ambient level (remember that the heater is still off). Note the temperature (voltage) of the water in the heater tank. This is the 'reference temperature'. Refer to Table 1 on page 18 of this guide for the voltage to temperature conversion of the temperature transmitters.

9) Adjust the setpoint so that it is equal to the reference temperature.

10) Switch the heater to 'External' and use the software to record the heater tank temperature, the flow in the heater loop, the setpoint and the output to the heater (controller output).

NOTE *The reservoir level will drop during this experiment and the low level circuit will switch off Pump 2 for a few seconds. This is normal and does not affect the experiment.*

11) Adjust the setpoint to correspond to a temperature increase of 2°C above the reference temperature.

12) Note how long the system takes to adjust to the new heater tank temperature (it should be less than 30 minutes).

13) On the Mimic Panel, increase the speed of Pump 1 to maximum. Allow the system to stabilize (this should take less than 20 minutes). Note how the system changes the heater power to compensate. Adjust Pump 1 back to the flow of approximately 1 L/min and wait for the system to stabilize.

14) Reduce the setpoint an amount that corresponds to 2°C and note how the system responds.

15) Draw a block diagram of the system.

Questions

- How does the response speed of the temperature control loop compare with the speed of the level and flow control loops in earlier experiments?
- Does the temperature control loop respond faster to increases or decreases in setpoint?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

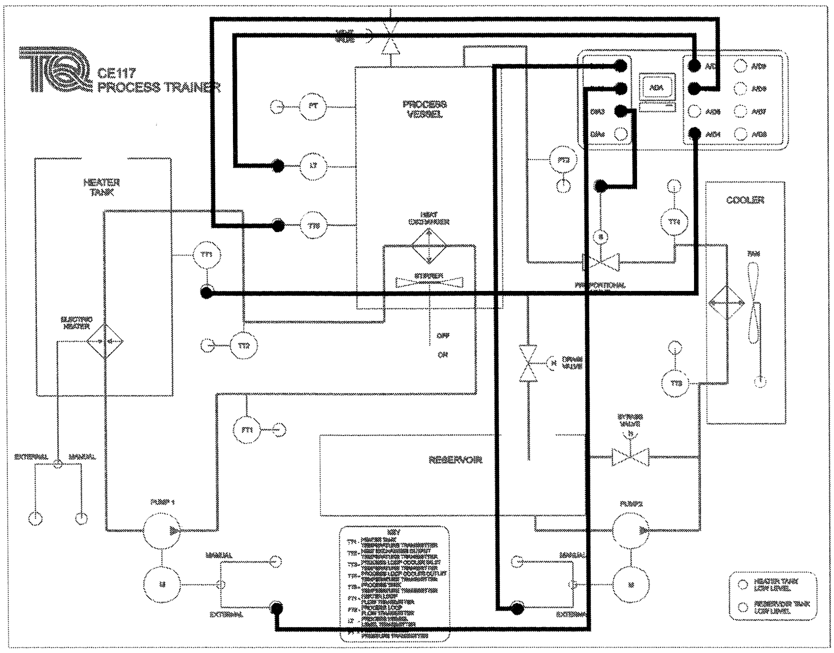

Figure 71 Connections For Experiment 6

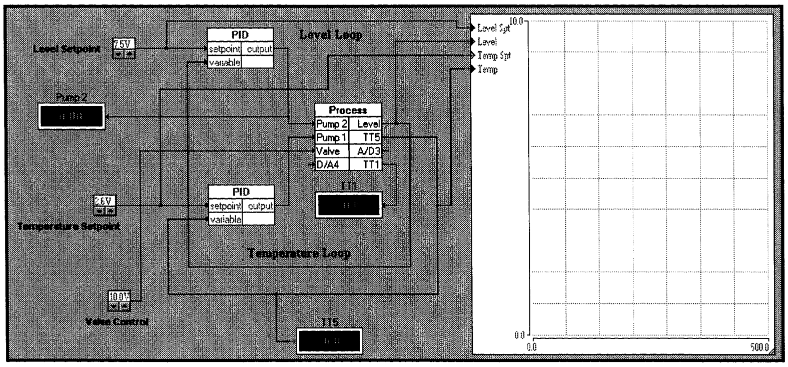

Figure 72 Screenshot of Experiment 6

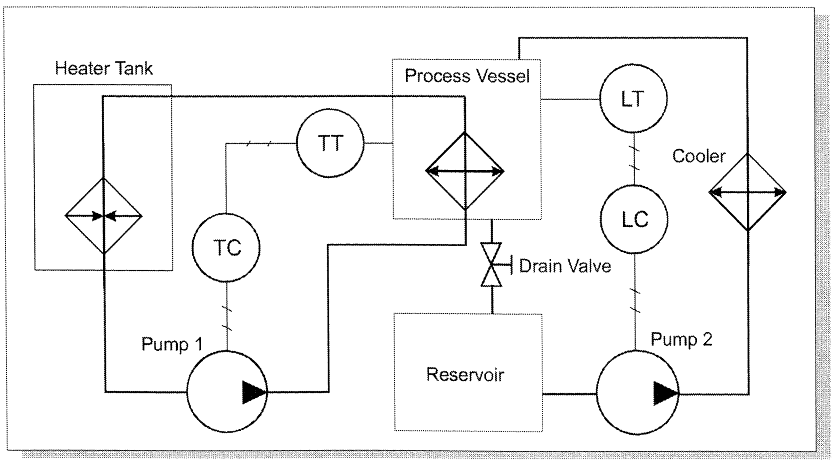

Figure 73 Schematic of Experiment 6

.9 Experiment 6: Temperature and Level Control of the Process Vessel

Objects

- To control the temperature in the process vessel by adjustment of flow in the heater loop.
- To control the level in the process vessel.
- To show the effect on each control loop as temperature and level setpoints are altered.

Procedure

1) Start the CE2000 software and load file 'exp6-1.ict'. Connect the CE117 Mimic Panel as shown in Figure 71. On the software, adjust the voltage to the proportional valve to 10 V (fully open). Analogue signals will pass from the ADA section to the valve and the pumps, and from the process vessel level and temperature transmitters back to the ADA section.

2) On the Mimic Panel, set the heater control to 'Manual' and adjust to full power. Set the cooler fan to maximum speed. Set both pump switches to 'External'. Close the loop bypass valve, fully open the process vessel drain valve and the air vent. Switch on the stirrer.

3) On the software, the blocks titled 'PID' are three term controllers, one controls the heater loop pump (temperature control), the other controls the process loop pump (level control). The proportional, integral and derivative values in the controllers are already set to:

   Proportional gain - 10
   Integral - 0.1
   Derivative - 0 (zero)

4) There are two setpoints, one for the **temperature** of the process vessel, the other for the **level** of the process vessel. Run the software and adjust the **temperature setpoint** to correspond to the temperature of the process vessel, indicated by the TT3 display, this is the reference temperature. Adjust the **level setpoint** to 7.5 V (the water in the process vessel must just cover the heat exchanger, so you may need to adjust the level setpoint slightly to achieve this).

5) Increase the **temperature setpoint** so that it is 5°C higher than the reference temperature. Refer to Table 1 on page 18 of this guide for the voltage to temperature conversion of the temperature transmitters. Note how long the process takes to adjust to the new heater tank temperature (it should be less than 10 minutes).

6) Increase the **level setpoint** by 1 V and note how both control systems respond. The level control loop moves to the new desired level. The temperature of the tank begins to drop, but the temperature control loop responds and returns the temperature to the desired value.

7) Increase the **temperature setpoint** by approximately 10% and note that only the temperature control loop responds (the temperature control does not influence the temperature control loop).

8) Draw a block diagram of the system.

Questions

- How well does whole process operate?
- How does the response speed of temperature control compare with level control?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

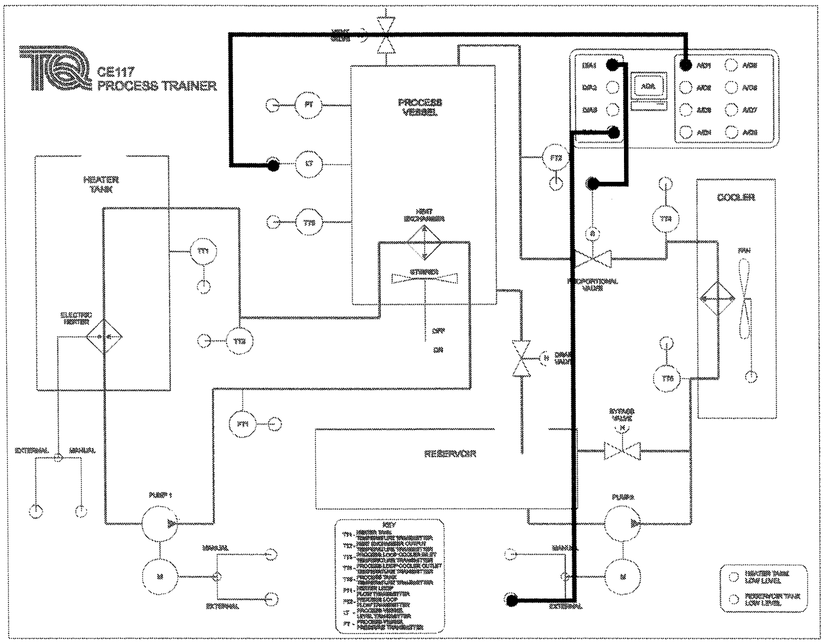

Figure 74 Connections for Experiment 7

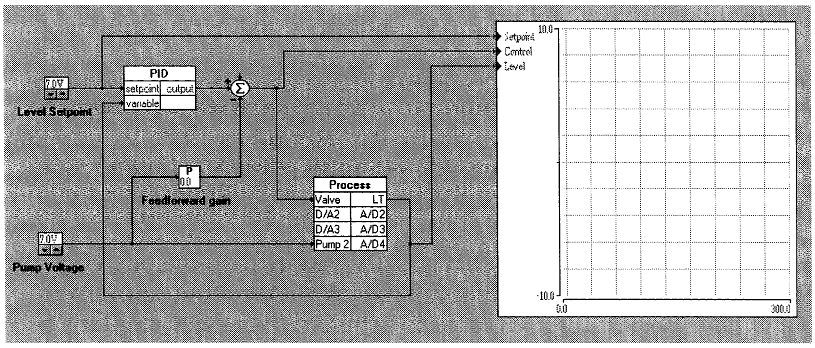

Figure 75 Screenshot of Experiment 7.

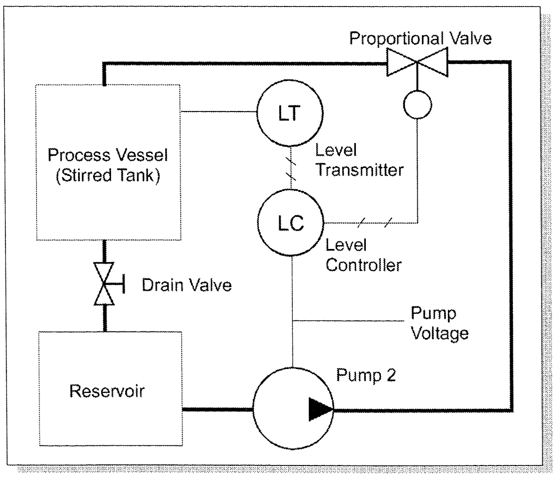

Figure 76 Schematic of Experiment 7

10 Experiment 7: Level Control by Valve Position with Feedforward of Pump Speed

Object

To control the level in the process tank by controlling the valve, and to notice the disturbance in the control system caused by changes in the speed of pump 2. To introduce feedforward of Pump 2 input voltage to reduce the disturbance.

Procedure

1) Start the CE2000 software and load file 'exp7-1.ict'. Connect the CE117 Mimic Panel as shown in Figure 74.

2) On the Mimic Panel, set the heater control to 'Manual' and adjust to minimum power. Switch off the cooler fan and stirrer. Set pump 2 to external, open the drain valve in the process vessel and ensure that the bypass valve is closed.

3) Look at the CE2000 screen (or Figure 75). The system is set up for PI control of the process vessel using the valve position as the controlled variable. Because the pump speed may vary, there is a ***feedforward gain*** between the pump 2 input voltage and the output of the PID controller. Set the ***feedforward gain*** to zero. Set the PID controller to:

   Proportional gain - 5
   Integral - 0.2
   Derivative - 0 (zero)

4) Set the level setpoint and the pump voltage to 7 V. Run the software. Let the system stabilize, it will take approximately 5 minutes for the process vessel level (LT) to settle within 10% of the level setpoint.

5) Increase the pump voltage from 7 V to 10 V. Notice that the change in pump speed causes a disturbance to the control system and the controller must adjust the valve position to compensate. Allow the system to settle.

6) Decrease the pump voltage from 10 V to 7 V. Again, notice the effect of the disturbance on the controller. Allow the system to settle.

7) Increase the feedforward gain from 0 to 0.2. Allow the system to settle.

8) Repeat steps 5 and 6. Note that the disturbance caused by the pump speed change is reduced.

9) Increase the feedforward gain from 0.2 to 0.3. Allow the system to settle.

10) Repeat steps 5 and 6. Compare the results with those obtained from the smaller feedforward gain.

11) Draw a block diagram of the system.

Question

- Discuss the effect of feedforward and how to set the feedforward gain correctly.

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

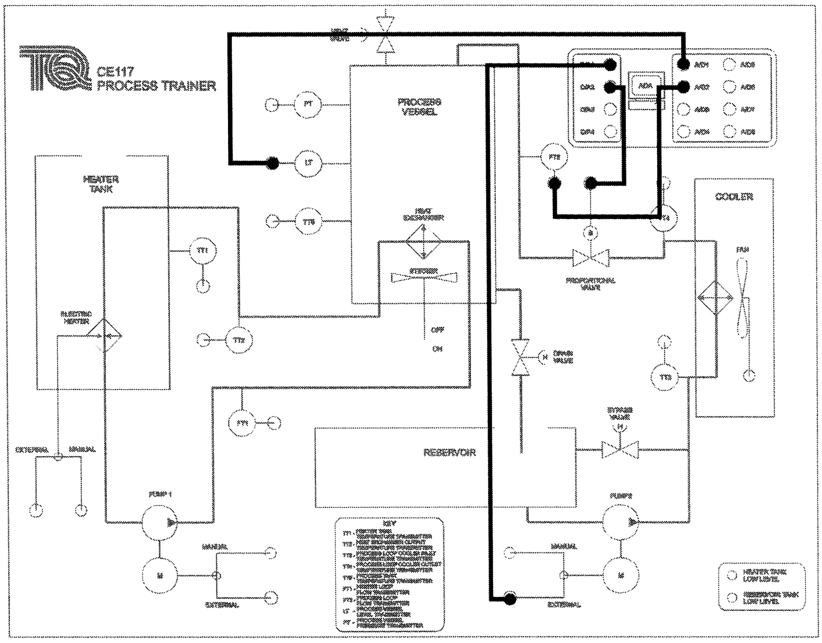

Figure 77 Connections for Experiment 8.

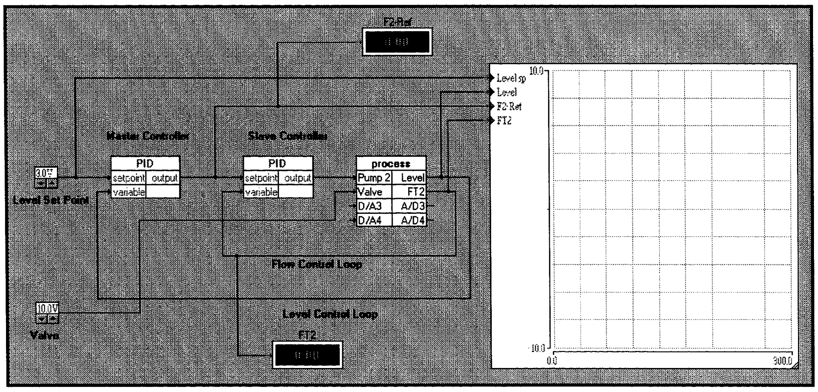

Figure 78 Screenshot of Experiment 8.

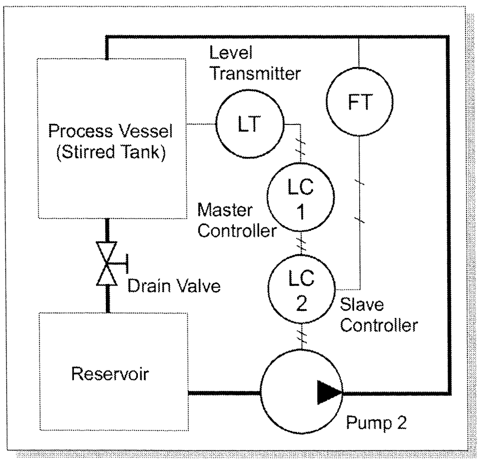

Figure 79 Schematic of Experiment 8

11 Experiment 8: Cascade Control of the Process Vessel Level

Object

To control the process vessel level by means of (local) cascade control.

In a cascaded control system there are a set of cascaded (sometimes called 'nested') control loops. In this experiment there are two cascaded loops: The inner loop (slave loop) controls flow through pump 2. The outer loop (master loop) controls the level in the process vessel.

Procedure

1) Start the CE2000 software and load file 'exp8-1.ict'. Connect the CE117 Mimic Panel as shown in Figure 77.

2) Make sure the process loop bypass valve is closed. Open the process vessel drain valve. Switch on the stirrer. Make sure that the air vent is open.

3) On the software, adjust the voltage to the proportional valve to 10 V (fully open). Analogue signals will pass from the ADA section to the valve and the pump, and from the process vessel level transmitter and flow transmitter back to the ADA section.

4) On the software, the two blocks titled 'PID' are three term controllers, one adjusts the process vessel level and provides the setpoint for the second 'slave' controller. The slave controller adjusts the flow of water in the process loop.

5) Set the reference level to 7 V. This gives a suitable mid-range setting for the level in the process vessel.

6) Set the master controller settings to:
   P = 20
   I = 1
   D = 0

   These settings will give a fast response.

7) Set the slave controller settings to:
   P = 0.25
   I = 0.1
   D = 0

8) Open the process vessel drain valve, set pump 2 switch to 'External' and run the software.

9) Allow the system to run for a few seconds and increase the level setpoint by 0.5 V. Note how the slave controller adjusts the **flow** of the loop and not just the **voltage** on the pump as in Experiment 6. This overcomes any 'deadzone' in the pump and gives a more responsive control.

10) Allow the system to stabilize, this will take less than 30 seconds. When the level is at a steady state value, reduce the setpoint down to 7 V again.

Low Gain Slave Controller Test

11) Make sure that the slave controller settings are:

    P = 0.25
    I = 0.1
    D = 0

    This is a low performance controller that will limit the performance of the master controller loop.

12) Run the experiment and allow the system to stabilize (approximately 20 seconds).

13) Increase the setpoint by 1 V. Note the step response of the master and slave.

High Gain Slave Controller Test

14) Reduce the setpoint back to 7 V.

15) Set the slave controller to:

    P = 1
    I = 1
    D = 0

    This is a higher performance controller that will make the slave controller respond more quickly and allow the master control loop to respond faster.

16) Run the experiment and allow the system to settle (approximately 20 seconds).

17) Increase the setpoint to 8 V and note the more responsive behaviour of the control loop.

18) Draw a block diagram of the system.

Questions

- How does the change in gain affect the performance of the system?
- what do you notice about the size of the initial signal output from the master controller? Is this realistic, and how could it be improved?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

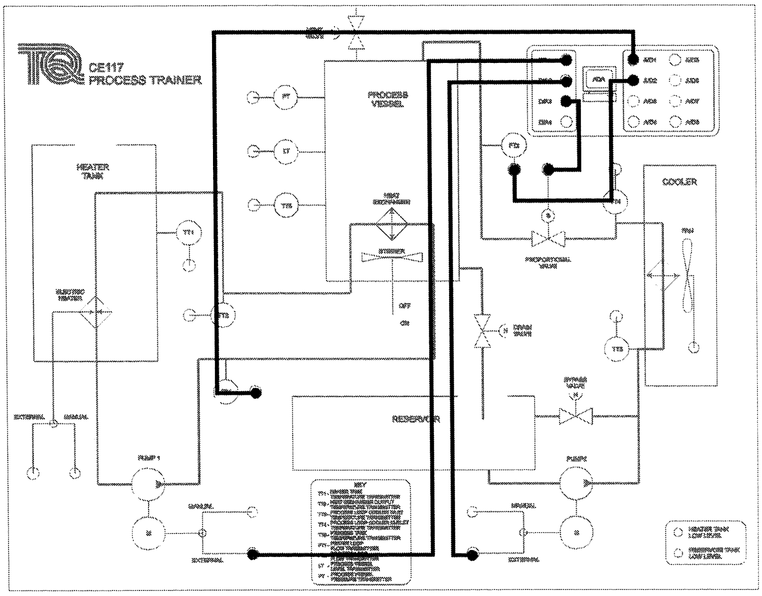

Figure 80 Connections for Experiment 9

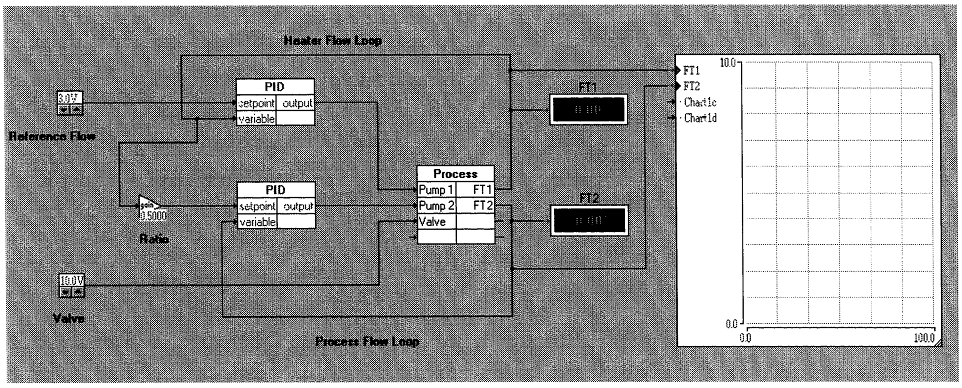

Figure 81 Screenshot of Experiment 9

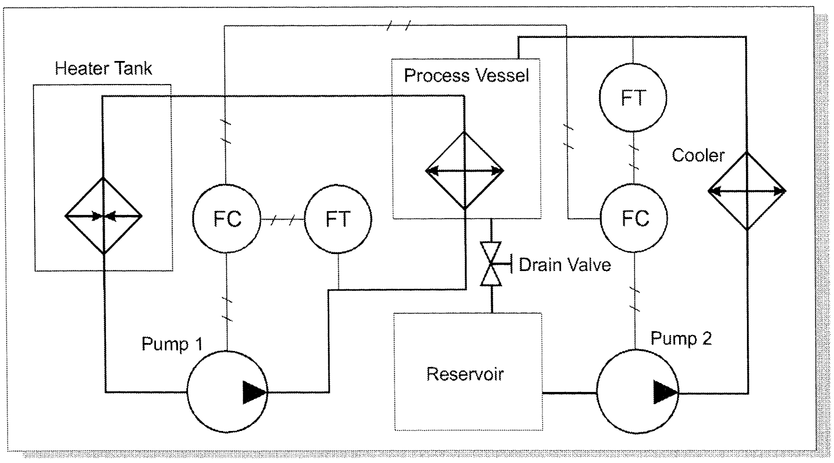

Figure 82 Schematic of Experiment 9

12 Experiment 9: Ratio Control of Process and Heater Loop Flow

Object

To implement a ratio controller that maintains the ratio of the flow rates in the heater and process loops at a set value.

Procedure

1) Start the CE2000 software and load file 'exp9-1.ict'. Connect the CE117 Mimic Panel as shown in Figure 80.

2) Create a blank results table similar to Table 8.

3) Make sure the process loop bypass valve is closed. Open the process vessel drain valve. Switch off the stirrer. Open the air vent.

4) Set both pump switches to 'External'. Make sure the cooler is set to minimum (off).

5) In the software, adjust the valve voltage to 10 V (fully open). Set the 'Ratio' block gain to 0.5.

6) Set both controllers to:
P = 5
I = 0.5
D = 0

7) Set the reference flow to 3 V. Run the program and confirm that the heater flow loop works correctly. You should note a steady value of 3 V at FT1.

8) Draw a block diagram of the system.

Test 1

9) Make sure that the ratio gain is set to 0.5 and the reference flow is set to 3 V.

10) Run the program, wait for the flows to stabilize and record them in your table.

Test 2

11) Increase the reference flow from 3 V to 3.5 V.

12) Wait for the flows to stabilize and record them in your table.

Test 3

13) Increase the ratio gain to 1. Reduce the reference flow to 3 V.

14) Wait for the flows to stabilize and record them in your table.

Test 4

15) Increase the reference flow from 3 V to 3.5 V.

16) Wait for the flows to stabilize and record them in your table.

Questions

- What is the relationship between the flow rates, the reference flow and the ratio gain?
- In what type of application would this control system be useful?

Parameter	Test 1	Test 2	Test 3	Test 4
Reference Flow	3 V	3.5 V	3 V	3.5 V
Heater Loop Flow (FT1)				
Ratio Gain	0.5	0.5	1	1
Process Loop Flow (FT2)				

Table 8 Blank Results Table

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

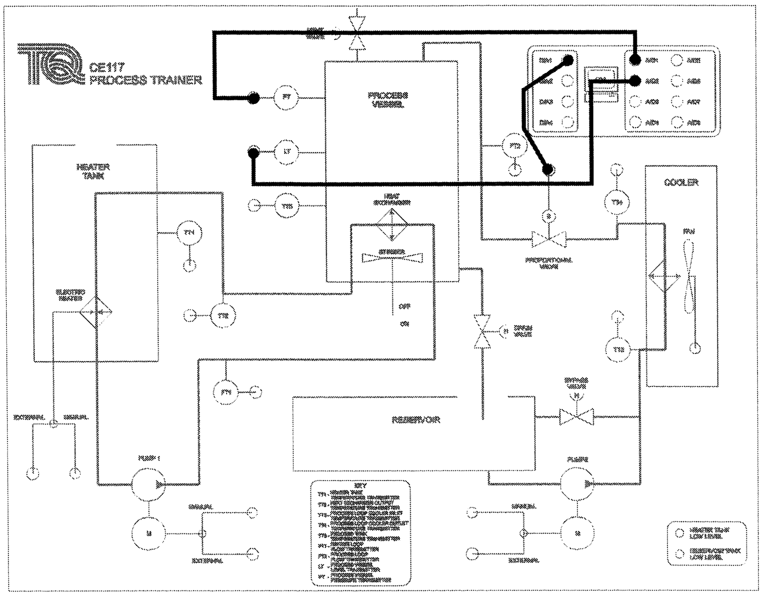

Figure 83 Connections for Experiment 10 Procedure 1

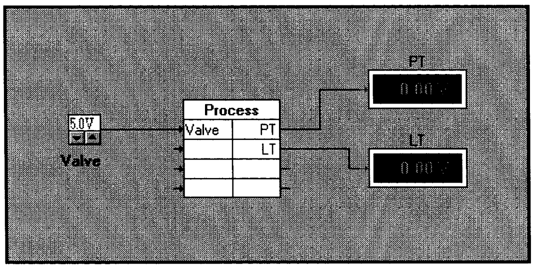

Figure 84 Screenshot of Experiment 10 Procedure 1

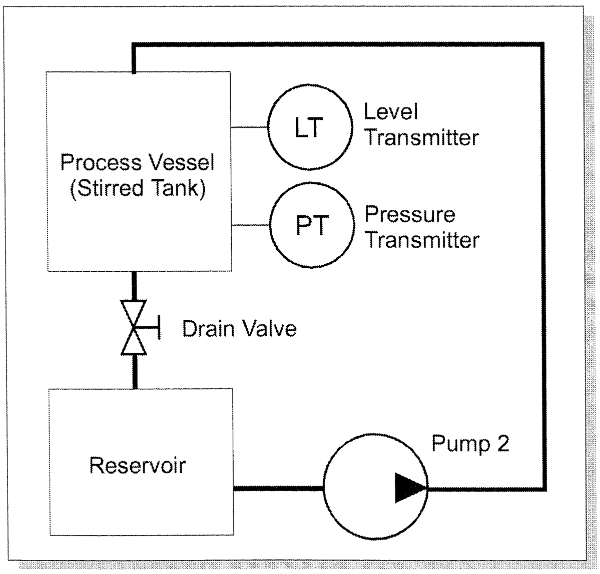

Figure 85 Schematic of Experiment 10 Procedure 1

13 Experiment 10: Pressure Control of the Process Vessel

Object

To control the pressure in the process vessel by different methods.

Procedure 1 - Set-up and Calibration

1) Start the CE2000 software and load file 'exp10-1.ict'. Connect the CE117 Mimic Panel as shown in Figure 83.
2) Create a blank results table similar to Table 9.
3) Make sure that the reservoir fill level is correct. Close the process loop by pass valve and the drain valve. Switch off the stirrer.
4) Set the cooler fan to minimum (off) and make sure the heater is set to 'External'. Switch Pump 2 to 'Manual' and its manual control to minimum (off).
5) Use the manual control for pump 2 to raise the water level in the process vessel to 50 mm. The air vent is open at this point, so the air in the process vessel is at atmospheric pressure and should give 0 V from the pressure transmitter.
6) Shut the air vent.
7) Raise the level in increments of 10 mm up to 100 mm and record each reading in your blank results table (or use the CE2000 software). Note: Set the CE2000 software to the manual record setting to record the data at each increment (see the CE2000 Manual for more details).
8) From your results, plot a graph of the pressure transducer readings on the vertical axis against the level transducer readings (or use the software). This graph is a calibration graph for the pressure transducer.

Level (mm)	PT (V)	LT (V)
50		
60		
70		
80		
90		
100		

Table 9 Results for Experiment 10

Question

- Is the calibration graph linear?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

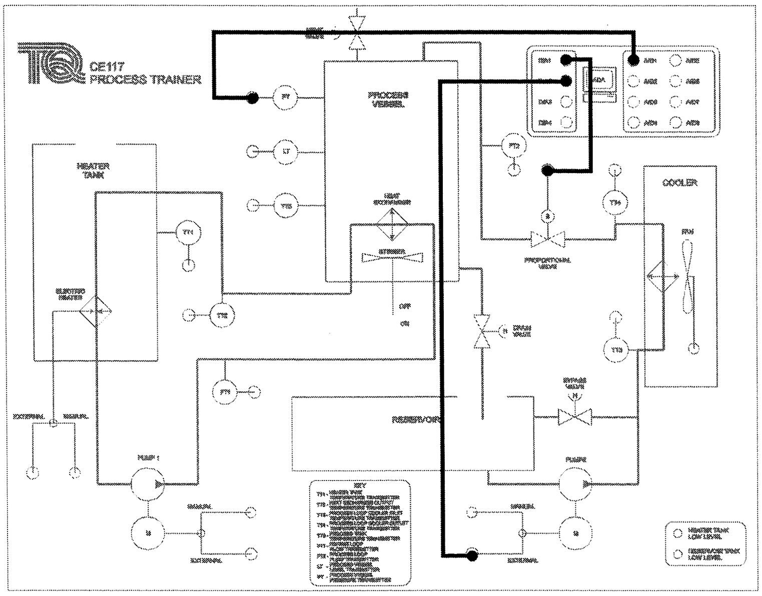

Figure 86 Connections for Experiment 10 Procedure 2

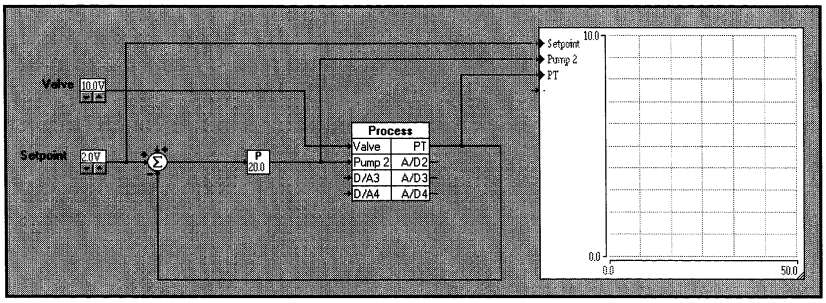

Figure 87 Screenshot of Experiment 10 Procedure 2

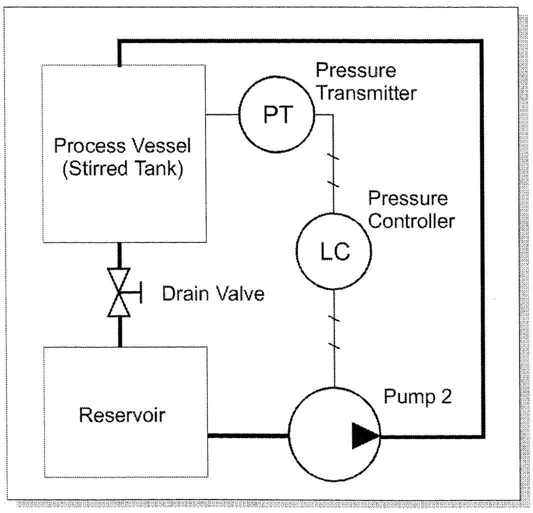

Figure 88 Schematic of Experiment 10 Procedure 2

Procedure 2 - Proportional Control

1) Start the CE2000 software and load file 'exp10-2.ict'. Connect the CE117 Mimic Panel as shown in Figure 86.

2) On the Mimic Panel, set Pump 2 to 'Manual' and minimum (off). Set the heater to 'External' and turn the fan control to minimum (off). Switch off the stirrer.

3) In the software, adjust the valve voltage to 10 V (fully open). Make sure that the Proportional Block (P) is set to 20.

4) Open the Air Vent and close the Drain Valve. Use Pump 2 to increase the Process Vessel level to 50 mm. Close the Air Vent.

5) In the software, set the pressure setpoint to 2 V. Set Pump 2 to 'External'.

6) Run the software and set it to record the results.

7) Increase the setpoint in increments of 0.5 V up to 4 V. After each increase, wait for the pressure to stabilize (should take less than two minutes). Note that it takes longer to stabilize as the pressure increases.

8) Stop the software and examine the results. Note that the system tries to match the changes in setpoint, but never actually reaches it. There is always an error - the 'steady state' error.

9) Repeat the test with the Proportional Block set to 10 and then 30.

10) Draw a block diagram of the system.

Questions

- How well does this proportional only system react to changes in setpoint?
- How does the steady state error relate to the Proportional Block gain?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.

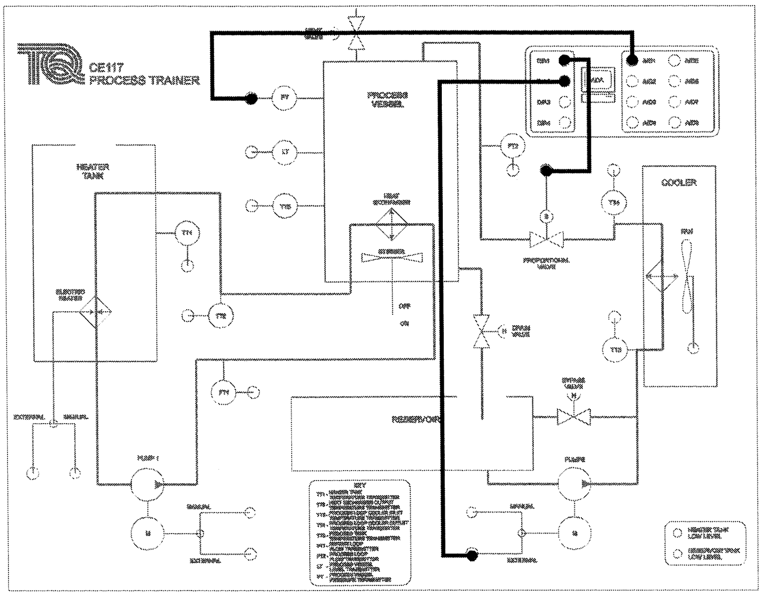

Figure 89 Connections for Experiment 10 Procedure 3 (Same as Procedure 2)

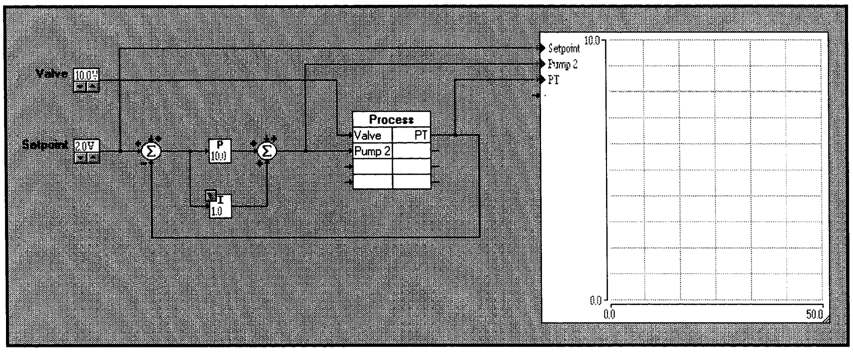

Figure 90 Screenshot of Experiment 10 Procedure 3

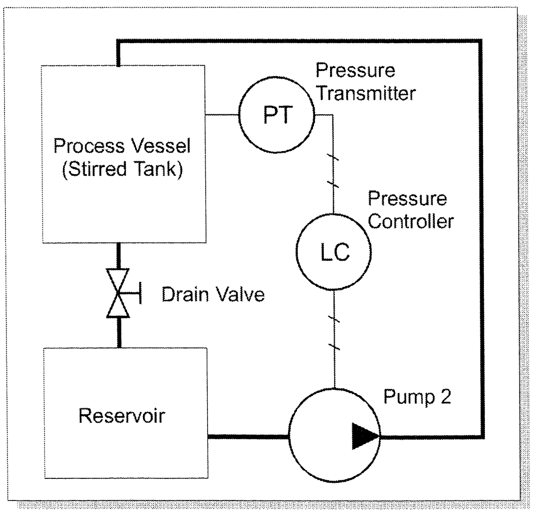

Figure 91 Schematic of Experiment 10 Procedure 3 (Same as Procedure 2)

Procedure 3 - Proportional Plus Integral Control

In Procedure 2, you found that there is always a steady state error when you use only proportional gain. This experiment shows that the addition of an 'Integral' term removes the error.

1) Start the CE2000 software and load file 'exp10-3.ict'. Connect the CE117 Mimic Panel as shown in Figure 89.

2) On the Mimic Panel, set Pump 2 to 'Manual' and its manual control to minimum (off). Set the heater to 'External' and turn the fan control to minimum (off). Switch off the stirrer.

3) In the software, adjust the valve voltage to 10 V (fully open). Make sure that the Proportional Block (P) is set to 20.

4) Open the Air Vent and close the Drain Valve. Use Pump 2 to increase the Process Vessel level to 50 mm.

5) Close the Air Vent.

6) In the software, set the pressure setpoint to 2 V. Set Pump 2 to 'External'.

7) Run the software and set it to record the results.

8) Increase the setpoint in increments of 0.5 V up to 4 V. After each increase, wait for the pressure to stabilize (should take less than two minutes). Note that it takes longer to stabilize as the pressure increases.

9) Stop the software and examine the results.

Questions

- How well does the Proportional and Integral system match the setpoint?
- How could the system be improved?

Further Experiments

Use the CE2000 software to develop your own ideas for changes to this experiment. Refer to 'Procedure 5 - To Edit and Build Your Own Circuits" on page 58 for more details.