Basic Process Control Unit

Instruction Manual

PCT40

ISSUE 10

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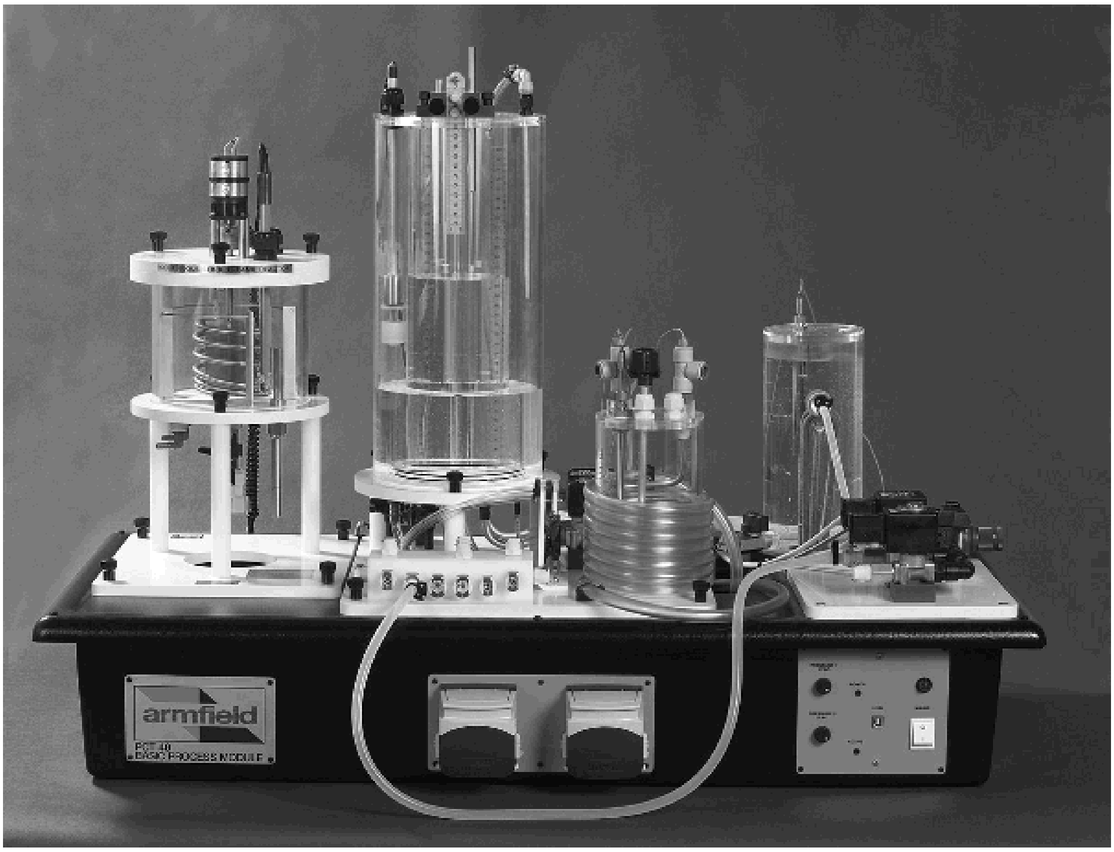
General Overview

The Armfield PCT40 system is designed for use in teaching a wide range of process control methods. The PCT40 basic unit is used under computer control to demonstrate a variety of process control loops. Processes such as level control, temperature control, flow control and pressure control can all be investigated, as can manual, on/off, proportional and PID control. The software included with the unit allows the student to change the control parameters and analyse the results from different configurations.

More advanced aspects of control can be addressed by adding optional extras to the basic system. The PCT 41 expands on the capabilities of the PCT40 with a wider range of control loops and strategies, including Remote Set Points, dual loops and Fluid Property Control (using Conductivity as a representative example). All these loops are under software control.

Other accessories are available, including a pH Probe (PCT42) for use with PCT41, an Electronic Console (PCT43) with commercial PID controller that allows the PCT40 to be operated directly without the need for a PC, and a Pneumatic Valve Module (PCT44) for those wishing to implement specialised demonstrations.



PCT40 Basic Process Control Unit with PCT41 Process Vessel Accessory

Equipment Diagrams

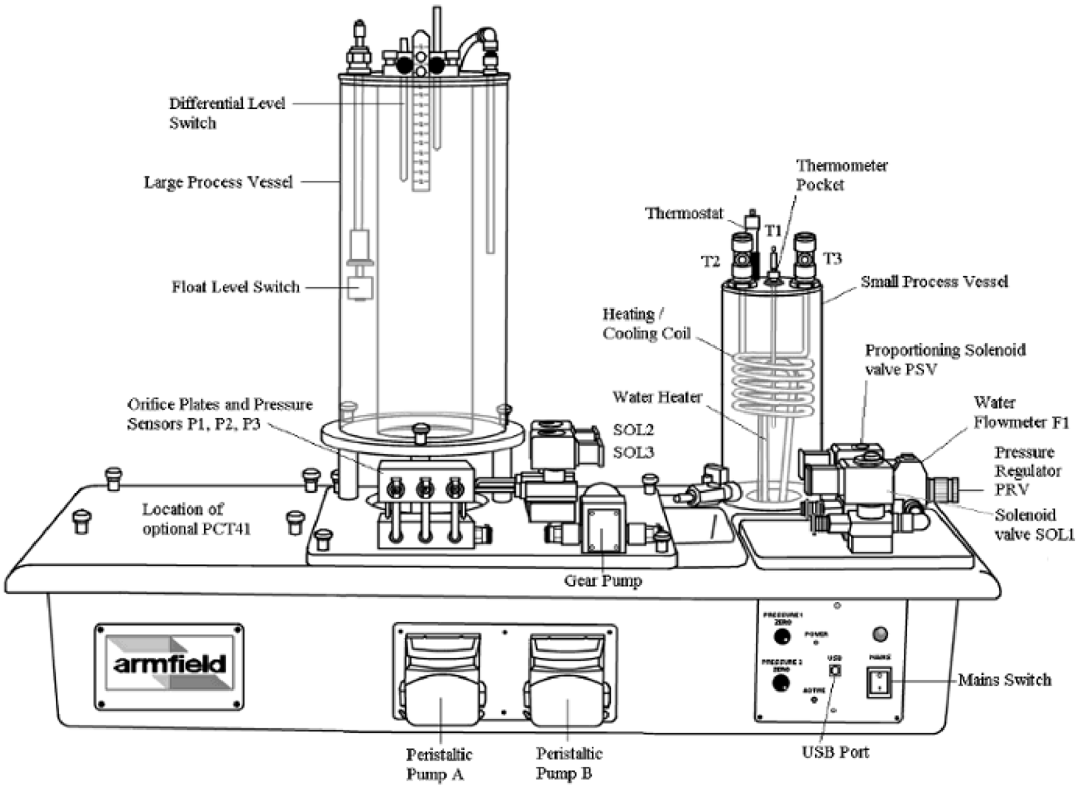


Figure 1 Front View of PCT40

Important Safety Information

Introduction

All practical work areas and laboratories should be covered by local safety regulations **which must be followed at all times**.

It is the responsibility of the owner to ensure that all users are made aware of relevant local regulations, and that the apparatus is operated in accordance with those regulations. If requested then Armfield can supply a typical set of standard laboratory safety rules, but these are guidelines only and should be modified as required. Supervision of users should be provided whenever appropriate.

Your **PCT40 Basic Process Control Unit** has been designed to be safe in use when installed, operated and maintained in accordance with the instructions in this manual. As with any piece of sophisticated equipment, dangers exist if the equipment is misused, mishandled or badly maintained.

Electrical Safety

The equipment described in this Instruction Manual operates from a mains voltage electrical supply. It must be connected to a supply of the same frequency and voltage as marked on the equipment or the mains lead. If in doubt, consult a qualified electrician or contact Armfield.

The equipment must not be operated with any of the panels removed.

To give increased operator protection, the unit incorporates a Residual Current Device (RCD), alternatively called an Earth Leakage Circuit Breaker, as an integral part of this equipment. If through misuse or accident the equipment becomes electrically dangerous, the RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

At least once each month, check that the RCD is operating correctly by pressing the TEST button. The circuit breaker **MUST** trip when the button is pressed. Failure to trip means that the operator is not protected and the equipment must be checked and repaired by a competent electrician before it is used.

Hot Surfaces and Liquids

The unit incorporates an electric heating element, and is capable of producing temperatures that could cause skin burns or scalds.

Ensure that the heating element is off when not required for the exercise being performed.

When using the heating element, before disconnecting any of the pipes or tubing:

- Stop all the pumps.
- Leave time for the water to cool
- Check that the temperature is at a safe level

Do not touch any surfaces close to ‘Hot Surfaces’ warning labels, or any of the interconnecting tubing, whilst the equipment is in use.

Chemical Safety

Details of the chemicals intended for use with this equipment are given in the Operational Procedures section. Chemicals purchased by the user are normally supplied with a COSHH data sheet which provides information on safe handling, health and safety and other issues. It is important that these guidelines are adhered to.

- It is the user's responsibility to handle chemicals safely.
- Prepare chemicals and operate the equipment in well ventilated areas.
- Only use chemicals specified in the equipment manuals and in the concentrations recommended.
- Follow local regulations regarding chemical storage and disposal.

Water Borne Hazards

The equipment described in this instruction manual involves the use of water, which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:

- Any water contained within the product must not be allowed to stagnate, ie. the water must be changed regularly.
- Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.
- Where practicable the water should be maintained at a temperature below 20°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.
- A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication "The Control of Legionellosis including Legionnaires Disease" - Health and Safety Series booklet HS (G) 70.

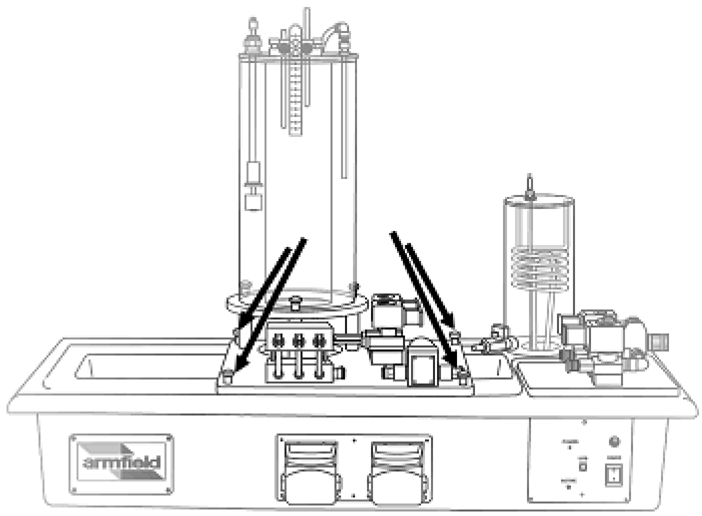
Description

Overview

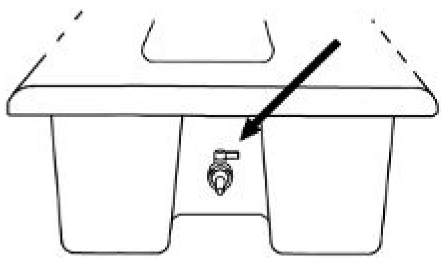
The PCT40 base unit consists of a moulded plinth, two process vessels, pumps and sensors as well as a mounting point and electrical connections for the optional PCT41 accessory.

Moulded Plinth

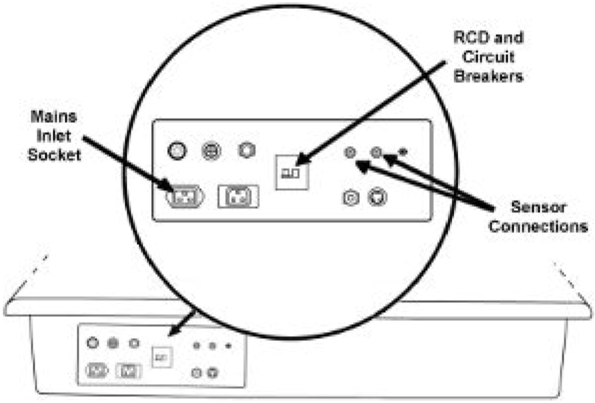
The base plate for the large process vessel is centrally located on a moulded plinth and secured using thumb nuts.



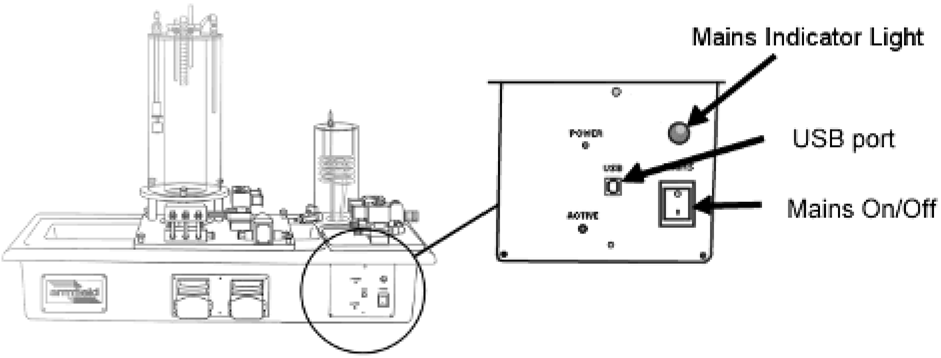
The plinth includes a drainage channel with a drain valve located at the end of the channel. The valve can be connected to a suitable drain using the flexible tubing supplied. The valve should be left open when connected to a drain



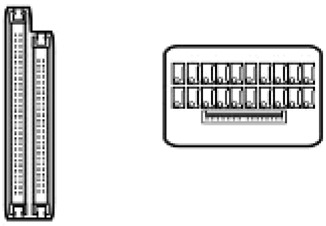
A mains power inlet socket and sensor connections are located at the rear of the plinth, which also incorporates an RCD and circuit breakers for electrical safety.



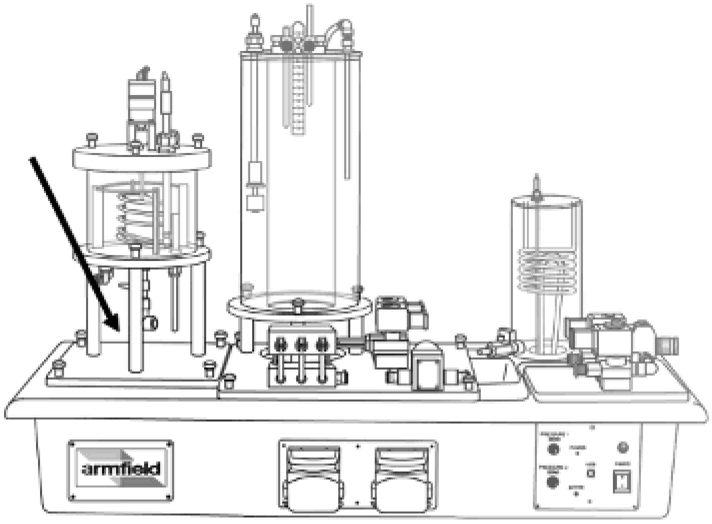
The front of the plinth incorporates the mains on/off switch and a USB socket for connection to a PC running the Armfield PCT40 software.



Both a 60-way I/O connector and a 50-way I/O connector are located on the right hand end of the plinth and may be used for connecting the PCT43 Electronic Console, when required.

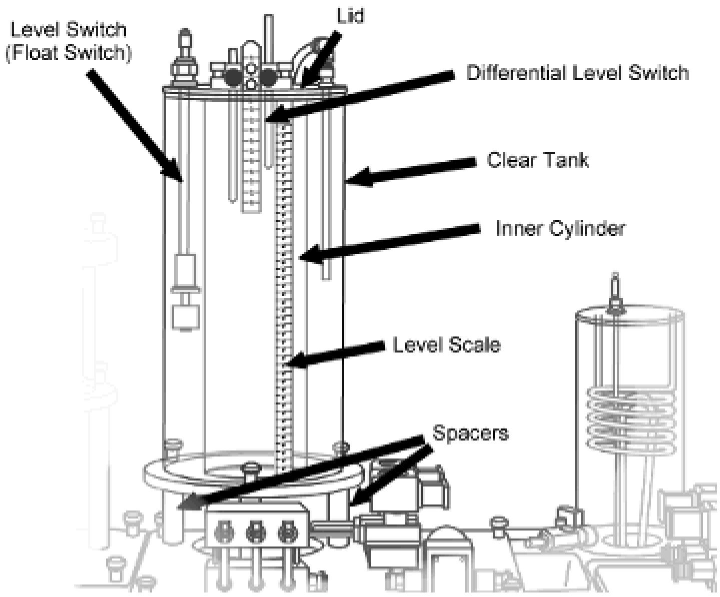


The left-hand end of the plinth includes a mounting point for the optional PCT41 Process Vessel Accessory.

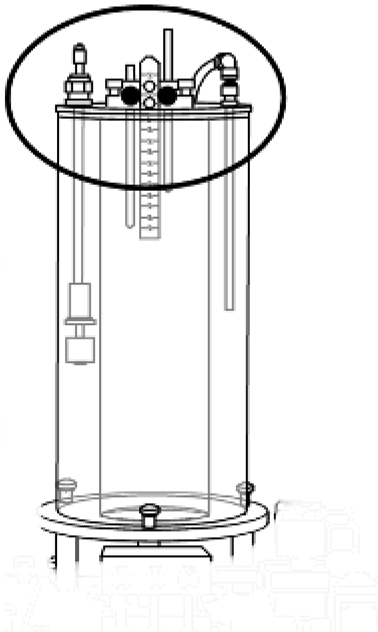


Other options such as the PCT44 Pneumatic Control Valve and PCT43 Electronic Console are designed to stand alongside the plinth when in use.

Large Process Vessel



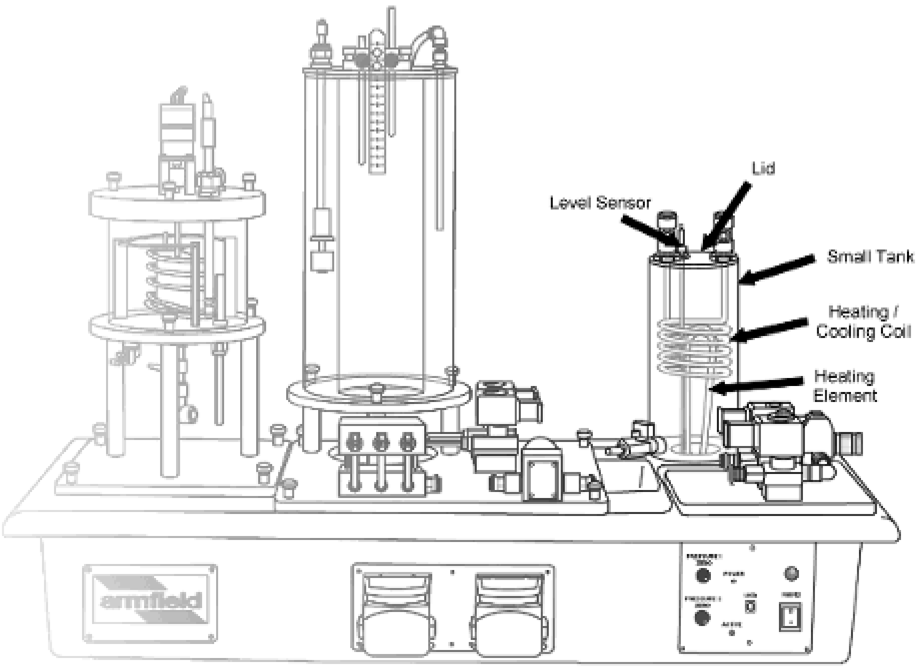
The large acrylic vessel has a removable tube inside to vary the volume of the vessel. When installed on the ‘O’ rings at the base, the tube creates an annular vessel of reduced volume. The vessel is mounted on spacers to allow access to the connections on the underside. The vessel includes a level scale. Tappings in the base of the vessel allow connections to pressure sensors, solenoid valves and pumps. A vertical overflow tube is included as a safety feature.



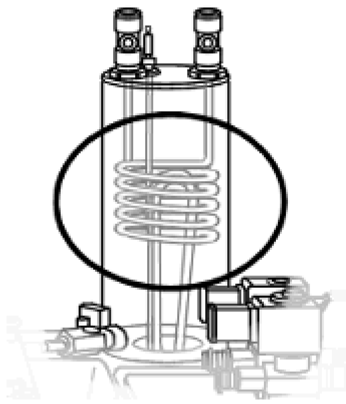
The lid of the vessel supports an adjustable height level switch, a differential level switch and a dip tube for filling or draining the vessel from the top using one of the pumps or control valves.

Small Process Vessel (Hot Water Tank)

The base unit includes a small clear acrylic process vessel at the rear. This vessel incorporates an electrical element for heating water. A thermostat and level detector are incorporated in the vessel to prevent the heater from operating if the water is too hot or the level in the vessel is too low. These safety devices are fixed and cannot be used for experimental purposes. The inlet and outlet on the side of the vessel have quick-release fittings. The vessel lid provides support for the heating/cooling coil.

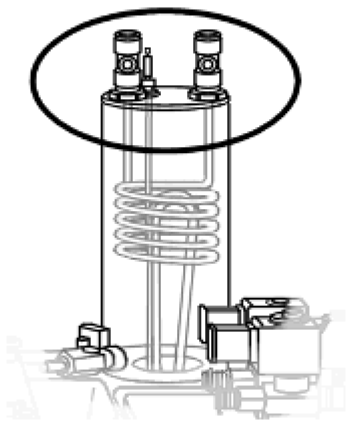


Heating/Coiling Coil

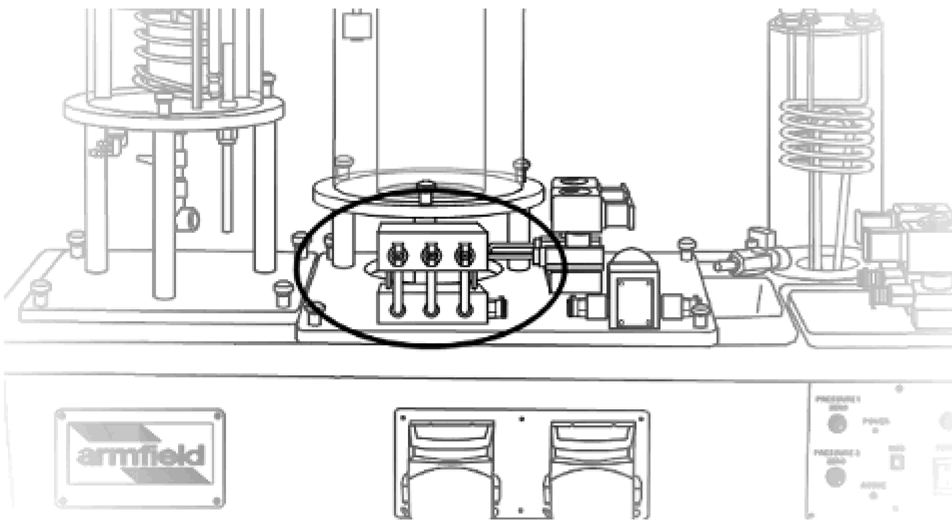


This is a stainless steel coil mounted on a lid that is designed to fit inside the small process vessel around heating element. Fittings at the inlet and outlet of the coil accommodate thermocouple-type temperature sensors and allow connection to the water supply.

The lid accommodates adjustable glands for a variable-height thermocouple sensor T1, a thermometer pocket and a temperature switch (thermostat). A spare gland allows an additional thermometer (not supplied) to be inserted into the vessel for the purpose of calibration.



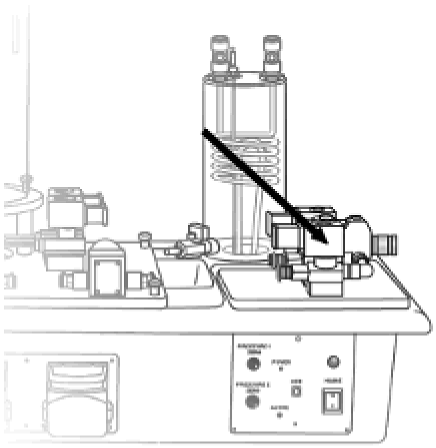
Manifold Block with Orifices and Pressure Tappings



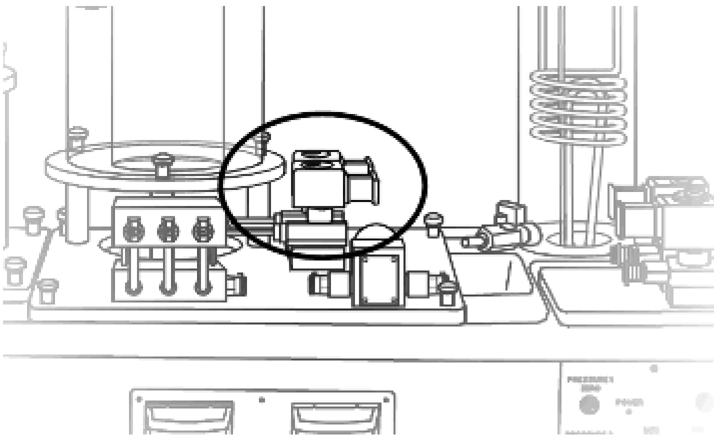
The manifold block incorporates three orifices with associated differential pressure sensors that can be used to measure flowrate The orifice associated with pressure sensors P1 and P2 is 1.9 mm diameter and suited to the low flow rates used in the PCT41 Process Vessel Accessory. In use the tube from the peristaltic pump is connected to the small quick release fitting at the front and the tube from the Process Vessel is connected to the ferrule at the rear so that the fluid flowing to the reactor vessel passes through the orifice.

The orifice associated with P3 is 3.7 mm diameter and suited to the higher flowrates used on PCT40. Fluid enters the orifice via a large quick release connector on the front of the block and exits via a Guest push fitting at the rear. An additional large quick release fitting (sealed) at the side of the block allows the flow from both peristaltic pumps to be combined before it passes through the orifice. The downstream connection from the orifice to P3 incorporates an in-line quick release connector. In normal use this is connected to give differential pressure that is related to flow. Alternatively the connection can be broken, with the sensor vented to atmosphere to allow line pressure to be measured.

Process valves SOL 1, 2 and 3

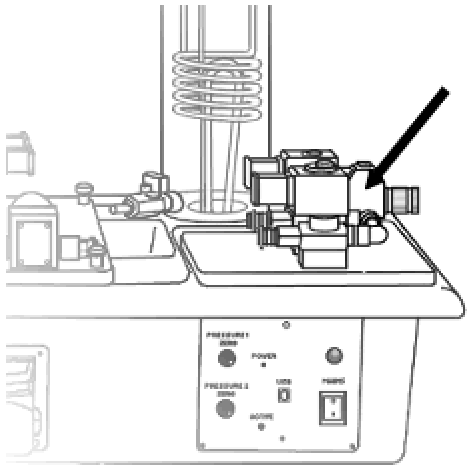


A Normally Closed solenoid valve, SOL 1, is located in front of the Proportioning Solenoid Valve for use in on/off control exercises.



Two Normally Closed solenoid valves, SOL 2 and SOL3, are fitted beneath the large process vessel. The outlet of both valves can be connected to a suitable drain using the flexible tubing supplied.

Pressure Regulator (PRV)

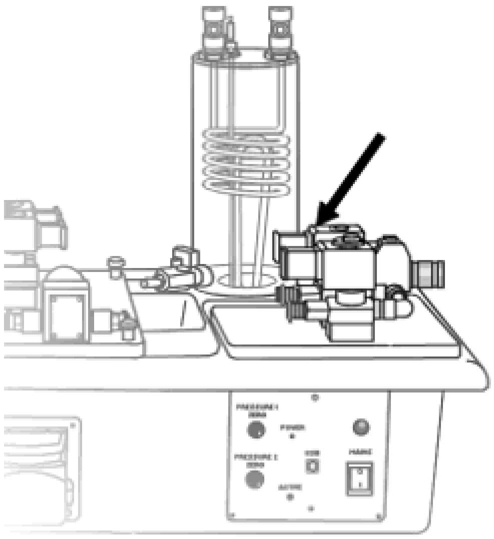


The mains water inlet is connected to a pressure regulating value with integral filter. The flow of water through the equipment can be varied by adjusting the setting of the regulator.

Inlet Flow Meter F1

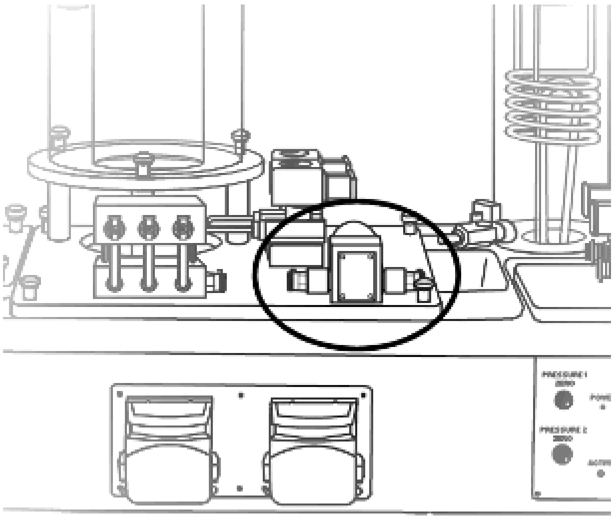
A turbine type flow meter is fitted in series with the mains water inlet to allow inlet flow rate measurement. The flow meter has a range of 0 to 1.5 litres/minute.

Proportioning Solenoid Valve PSV



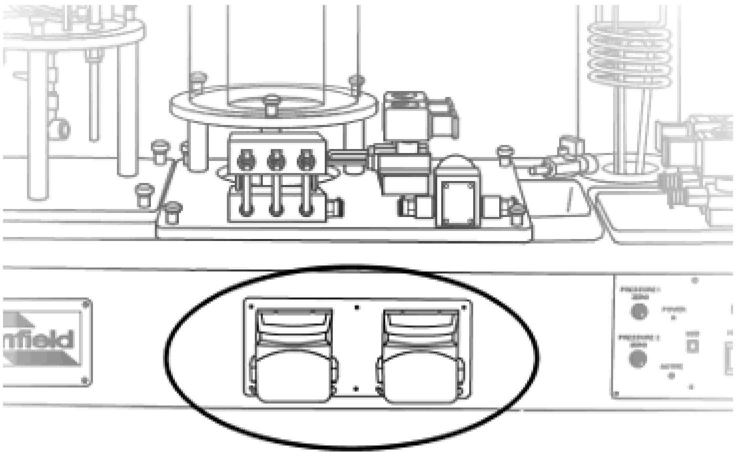
A proportioning solenoid valve is located near the mains water inlet. This is used in some process control exercises to demonstrate proportional control. At other times it may be used to regulate the inlet flow rate.

Gear Pump



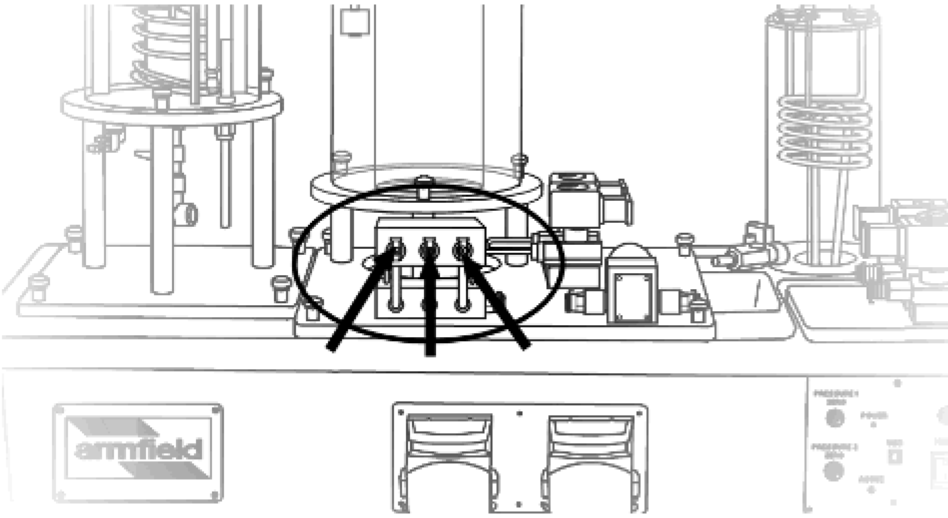
A DC motor-driven pump is located at the front of the plinth. This pump is used to pump hot water during heating and temperature control experiments.

Peristaltic Pumps A & B



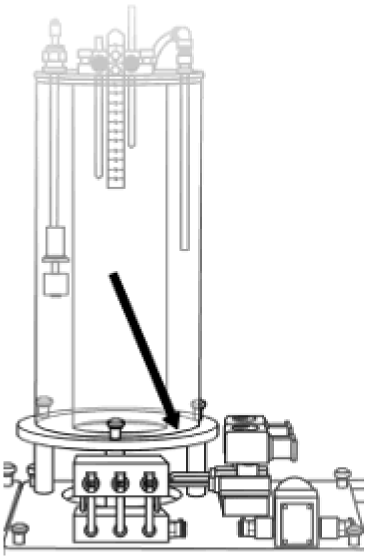
Two identical peristaltic pumps are located on the front of the plinth. These can take a wide range of silicone tubing, examples of which are included with the apparatus. The pumps may be operated individually or in parallel according to the control exercise. Pump A is located on the left-hand side, Pump B is located on the right-hand side.

Differential Pressure Sensors P1, P2 & P3



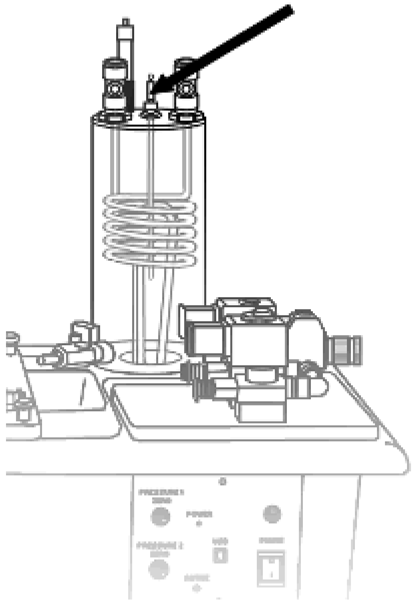
Three piezoelectric differential pressure sensors are located within the bottom section of the manifold block. Each is connected to read the differential pressure across an orifice in the top section of the block. P1 and P2 are small orifices used to measure the small flowrates associated with the optional PCT41. P3 is a large orifice for use with PCT40.

Level Sensor L1



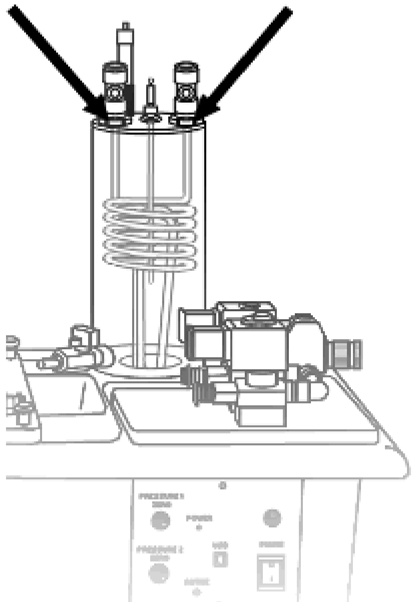
A piezoelectric pressure sensor is mounted in the base of the large process vessel. One side is connected to the inside of the process vessel, and the other is open to atmosphere, allowing the pressure in the process vessel to be measured relative to atmosphere. This sensor therefore measures the level of water in the vessel.

Temperature Sensor T1



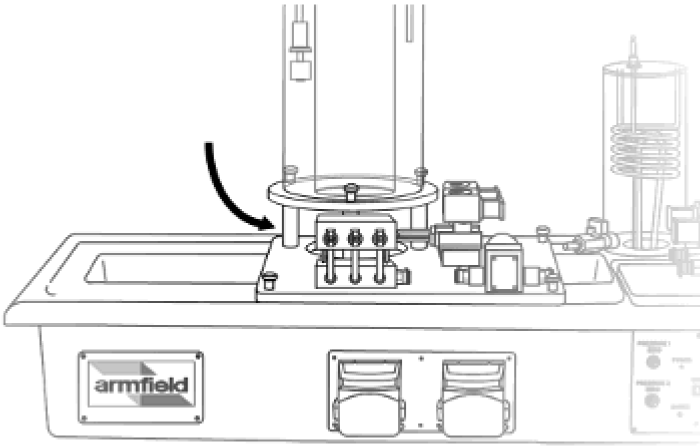
A type k thermocouple temperature probe mounted with the heating/cooling coil in the small process vessel. This probe is used to measure the fluid temperature inside the small process vessel.

Temperature Sensors T2 & T3



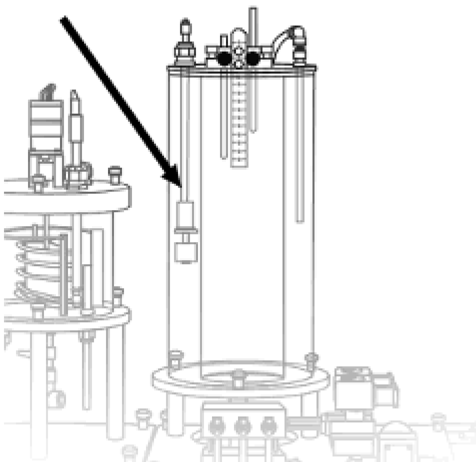
Two type K thermocouples located at the inlet and the outlet of the heating/cooling coil. These are used to measure the temperature of the fluid as it enters and leaves the coil.

Temperature Sensor T4



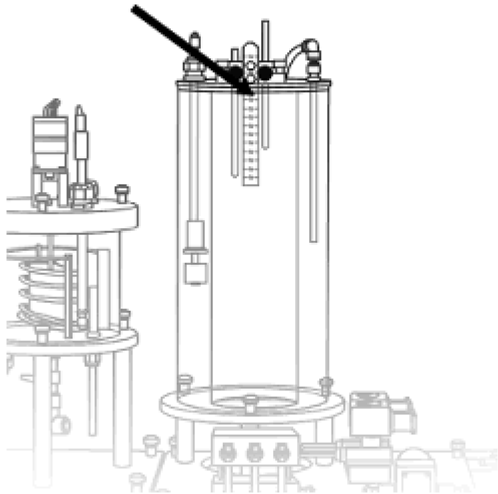
A type K thermocouple is located near the back of the base plate to the left of the large process vessel. This sensor is used during experiments utilising a holding tube, to measure fluid temperature at the outlet of the holding tube. This sensor is also used to measure temperature inside the reactor of the optional PCT41.

Level Switch



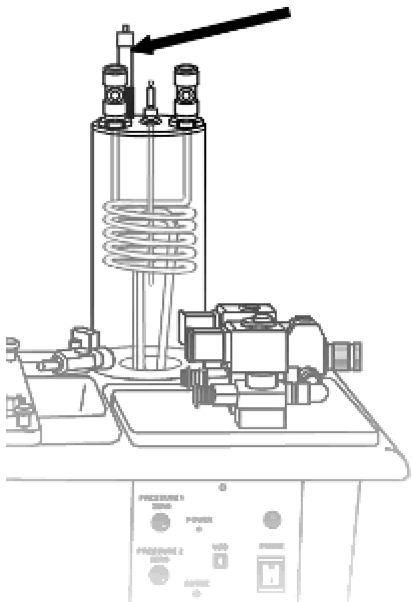
A height-adjustable fixed dead-band float switch.

Differential Level Switch



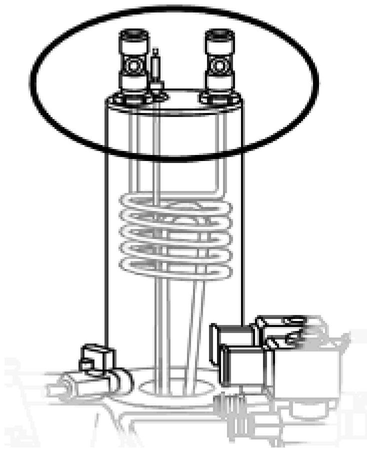
A variable dead-band conductive level switch consisting of fixed earth rod and adjustable high / low level electrodes on a support.

Thermostat (Temperature switch)



A fixed dead-band temperature switch consisting of a rod thermostat with adjustable set point.

Thermometer Pocket



A stainless steel thermometer pocket is located in the lid of the small process vessel. This slows the response of thermocouple T1 when it is inserted into the pocket.

Software

The PCT40 is supplied with an educational software package with a wide range of facilities and functions. The computer is the primary interface between the user and the equipment. The software displays real time process mimic diagrams with readings of the relevant sensor outputs and controls for the system inputs. Manual, On/off, time proportioned and PID control loops can be configured using ten predetermined student exercises.

All control and sensor signals can be logged continuously using the PC, and disturbances of known magnitude can be introduced. This eliminates the need for a separate process recorder or chart recorder for analysis of the process control responses. This software is compatible with PCs using Microsoft Windows^{TM} 98, 2000 and XP. The computer communicates to the PCT40 using a standard universal serial bus (USB) interface. Installation instructions are printed on the label of the software CD provided with the equipment. The software includes a comprehensive online Help Text.

The software also includes a driver to allow the users to write their own Labview software. (**Note:** Armfield only provide the driver, NOT the Labview software).

Installation

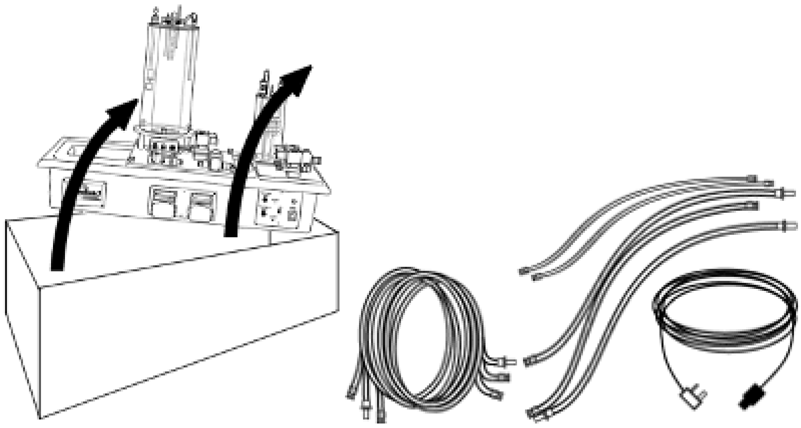
Advisory

Before operating the equipment, it must be unpacked, assembled and installed as described in the steps that follow. Safe use of the equipment depends on following the correct installation procedure.

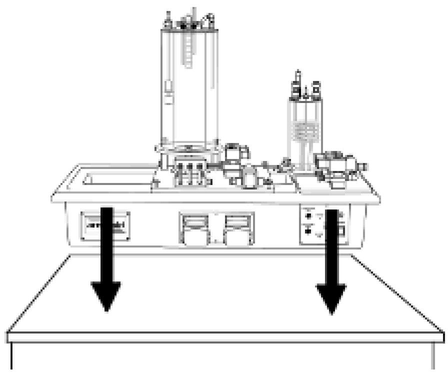
Installation Process

To install the equipment:

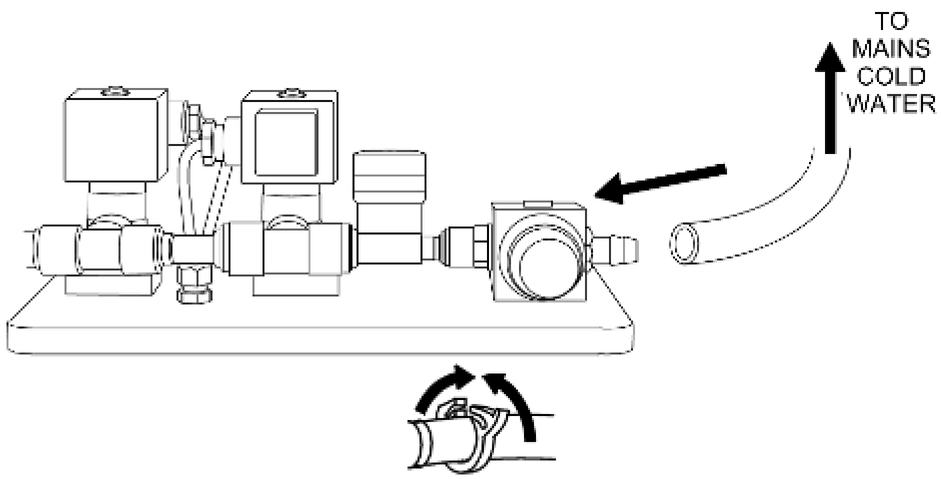
1. Take the PCT40 unit out of its packing box and remove all packaging. Retain all leads and tubing.



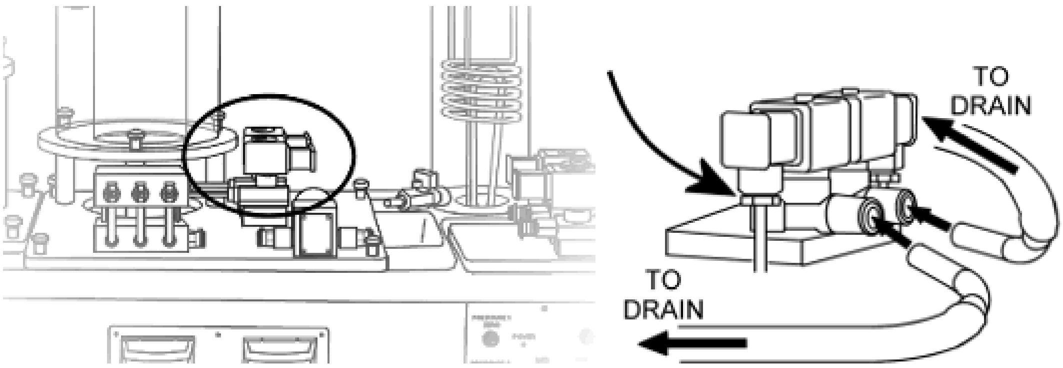
2. Place the PCT40 on a firm, level bench top or table.



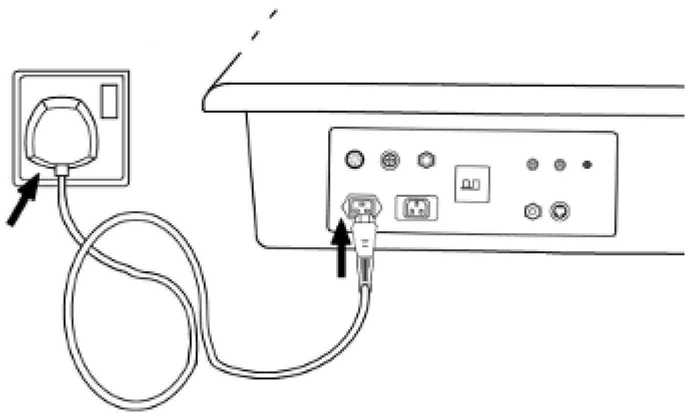
3. Connect the inlet to a supply of cold water using a standard ½" / 12.5mm length of standard hose (not supplied by Armfield), and secure using a suitable clip (not supplied).



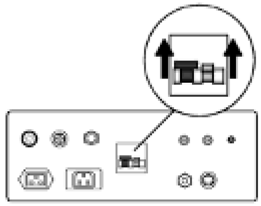
4. Connect the tubing supplied with right-angle (90°) Guest push fittings to the valves SOL2 and SOL3 beside the large process vessel.



5. Use the electrical cable provided, connect the power socket at the rear of the plinth to a suitable mains electricity supply.



6. Check that the RCD and circuit breakers at the back of the equipment are in the ON (up) position:



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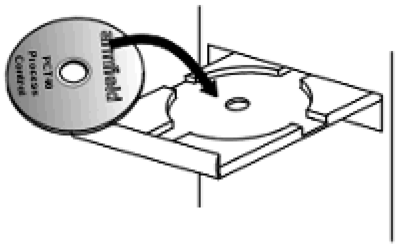
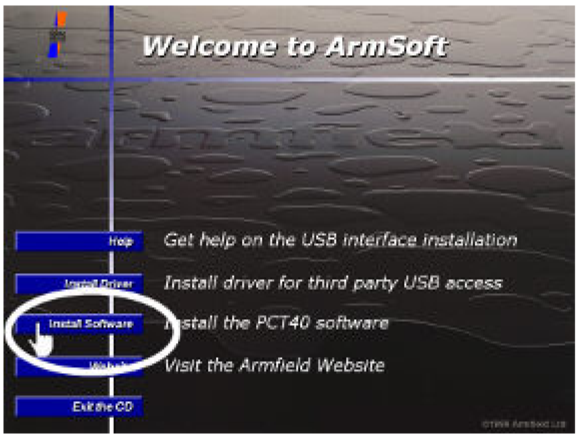
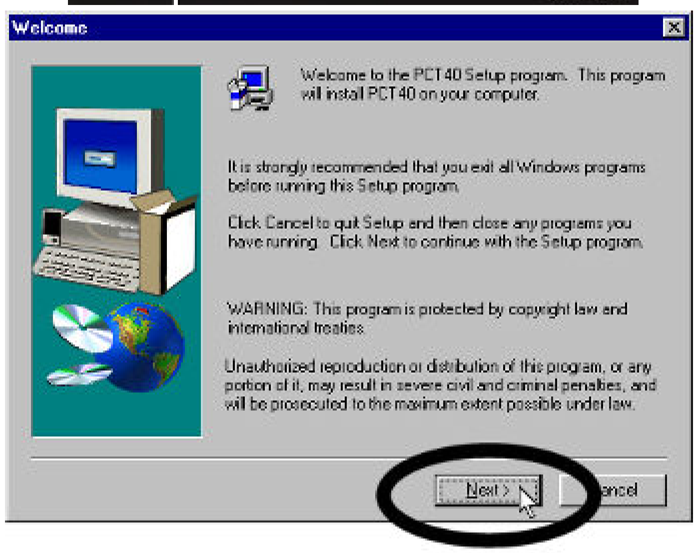
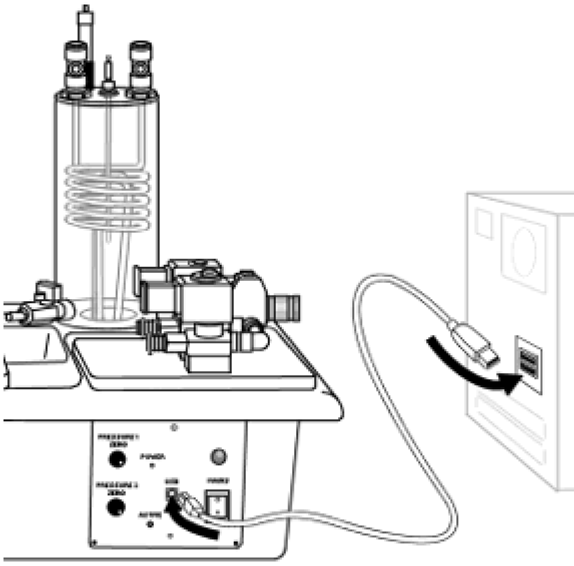


Insert the PCT40 software CD-ROM into the CD-R drive of a suitable PC. The installation program should autorun. If it does not, select ‘Run...’ from your Start menu, type run d:\setup where d is the letter of your CD-ROM drive. Follow the instructions on screen.

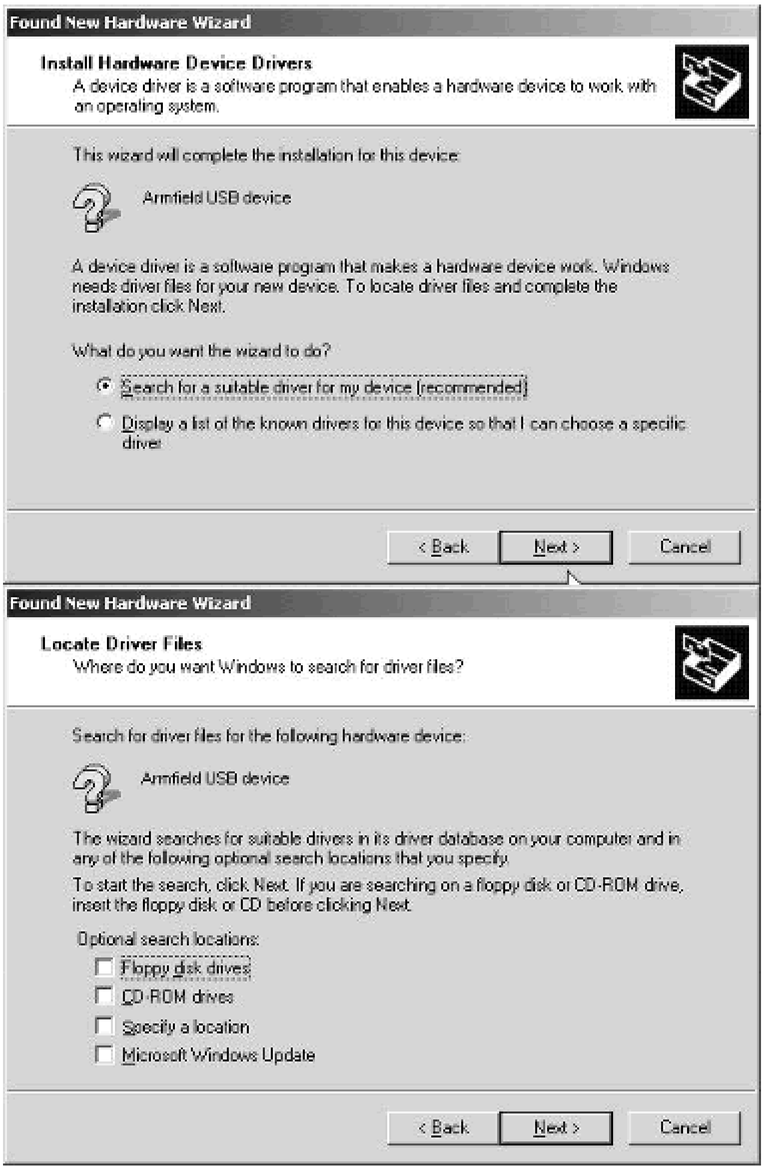




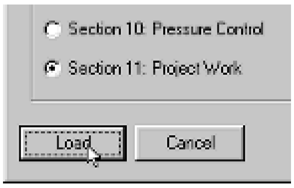
8. Connect the PCT40 to the PC. using the USB cable supplied.



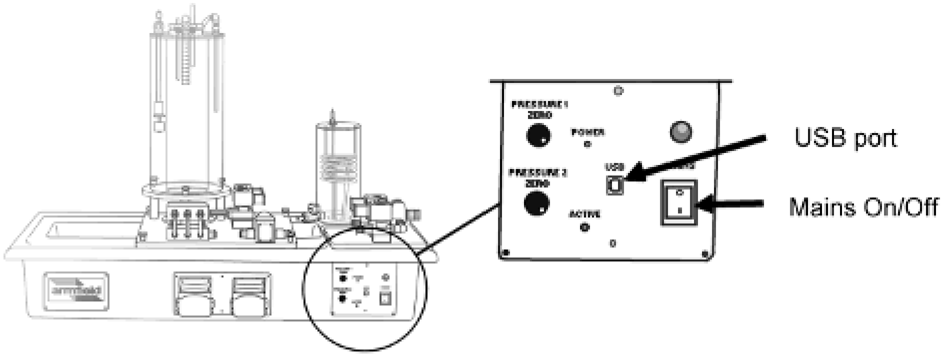
9. The computer should automatically detect the USB interface device. Follow the instructions to install the correct driver:



10. Run the PCT40 software and select the Project Work exercise.

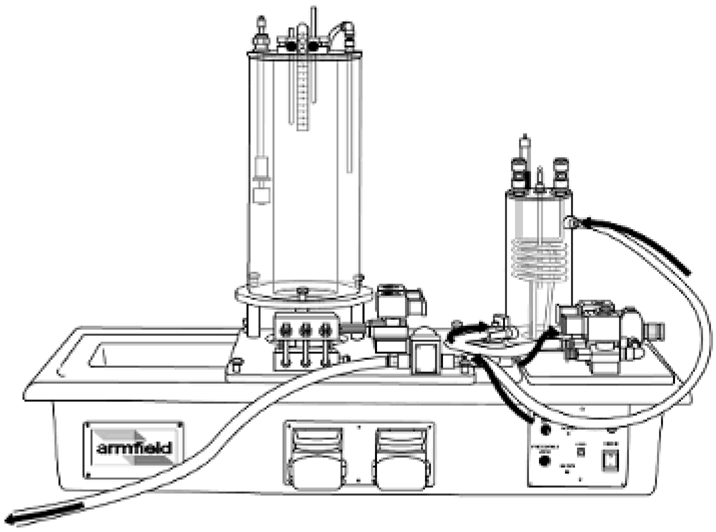


11. The on/off switch for the apparatus is located on the orange panel on the front of the plinth. Switch on the apparatus.

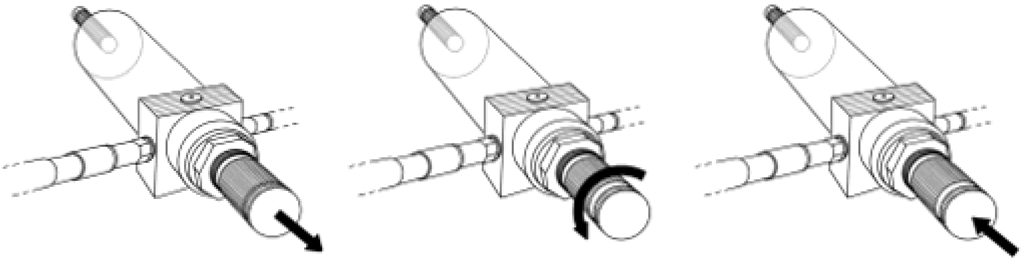


NOTE: The red and green LCD indicators on the front of the plinth are associated with the USB connection to the PC. These may be lit even if the PCT40 unit itself is switched off.

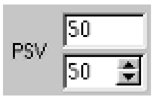
12. Using the flexible tubing provided, plumb the system as shown to allow testing of the apparatus.



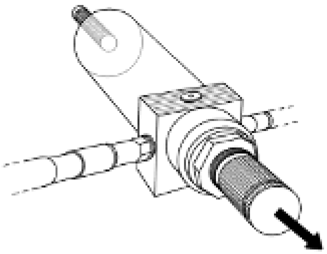
13. Close the pressure regulator: pull the grey knob away from the body of the regulator, turn the knob fully anticlockwise, then push the knob back in.



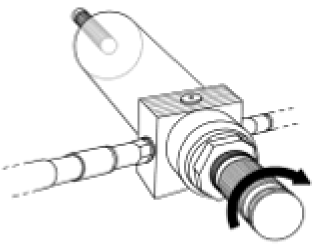
14. Open the PSV valve by typing a value of 50 into the display box on the software screen.

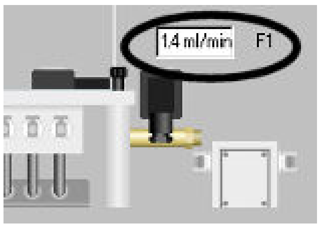


15. Pull out the grey knob on the right hand side of the regulator.

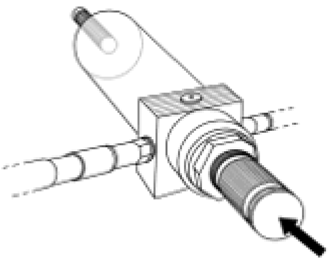


16. Turn the knob slowly in a clockwise direction (looking at end of knob) to set a flow rate of 1.4 L/min.

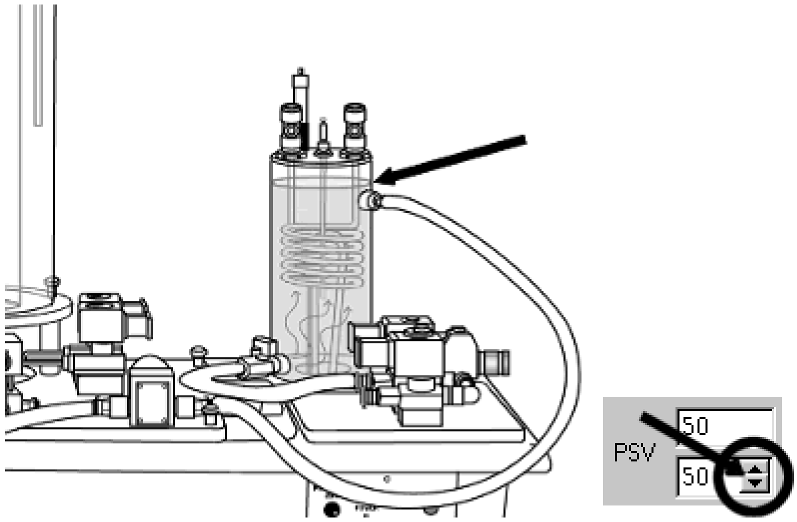




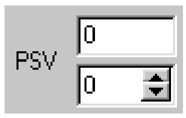
17. Lock the regulator setting by pushing the grey knob back towards the body of the regulator:



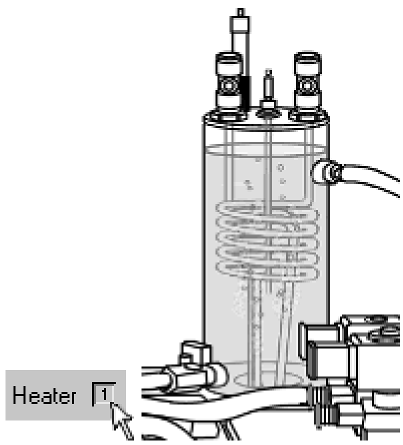
18. Alter the setting of the PSV using the arrow keys. Flow into the small process vessel should increase as the valve setting increases, and decrease as the setting decreases. After testing, set the valve to 50% until the small process vessel fills and water covers the tip of the level sensor.



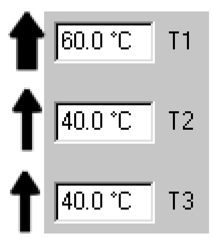
19. Close the PSV by setting it to 0%



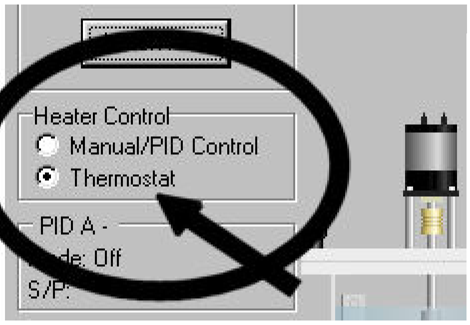
20. Switch on the heater. (SSR drive). The heater may be audible when on. Heated water will be visible as it rises from the element.

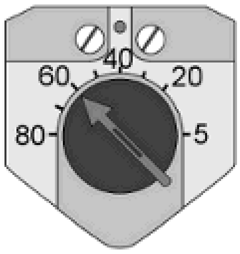


21. Check the temperature sensor readings on the software screen. T1 should increase as the temperature within the vessel rises; T2 and T3 should increase slightly as heat is conducted through the coil.

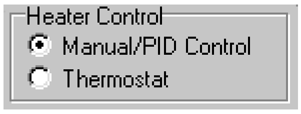


22. Set the Heater Control to ‘Thermostat’. On the top of the thermostat probe, set the control dial to 60 (°C). Check that the heater begins to operate.

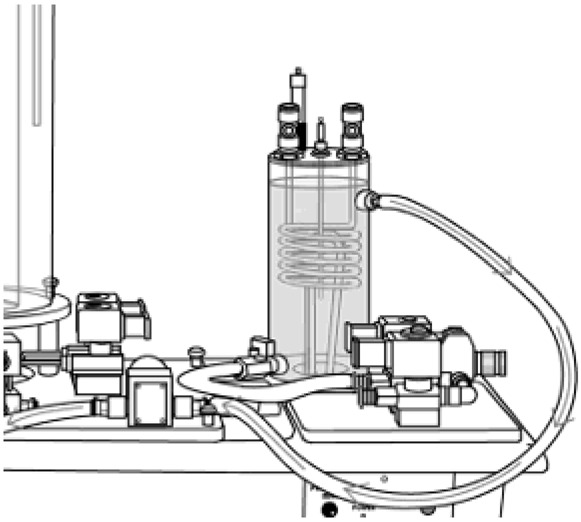




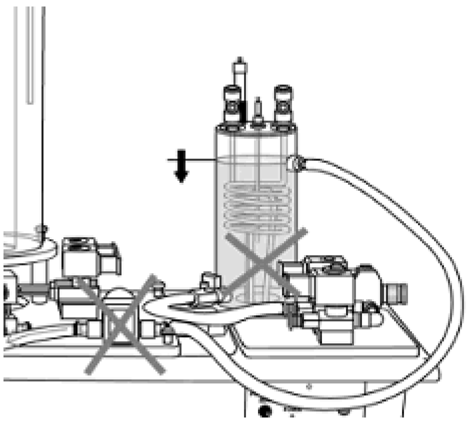
Set the Heater Control back to 'Manual/PID Control'.



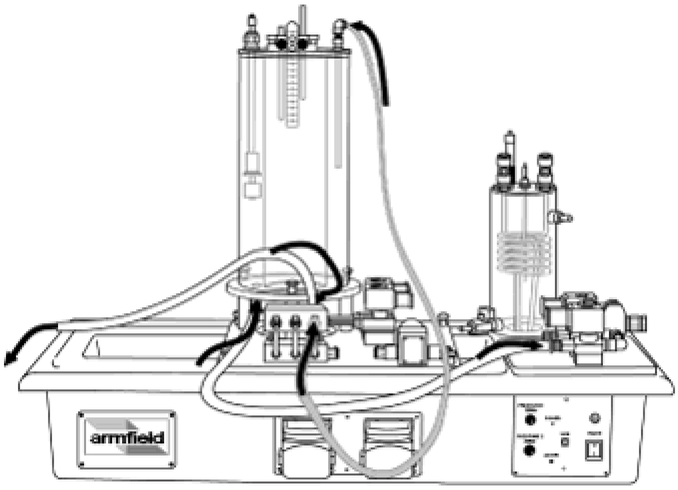
23. Set the Gear Pump Speed to 50%. The gear pump should begin to operate and water to flow from the small process vessel to drain.



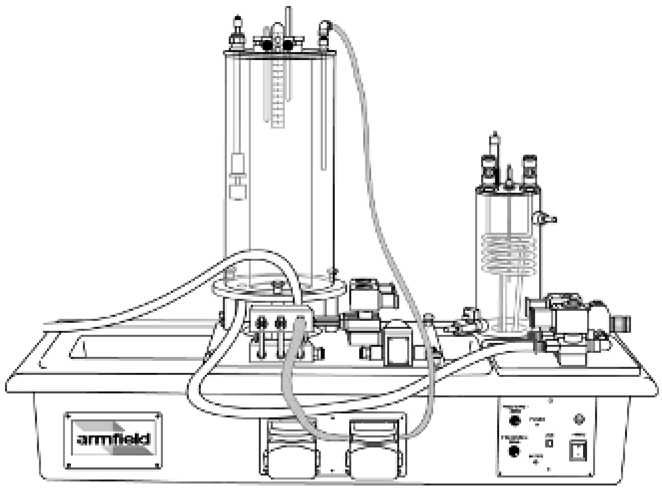
24. When the water level in the small process vessel drops below the tip of the level sensor, the gear pump and the heater should both stop working and the Level Low warning light should turn red. This shows that the safety cut-outs are working.

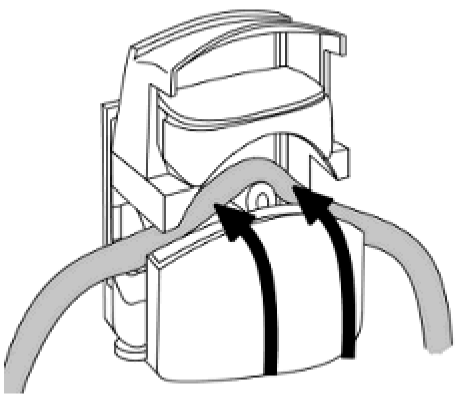


25. Change the plumbing to connect the apparatus in the following way.

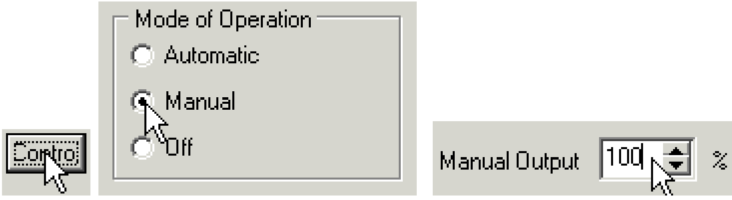


26. Insert the soft silicone tubing into the peristaltic pump as shown.

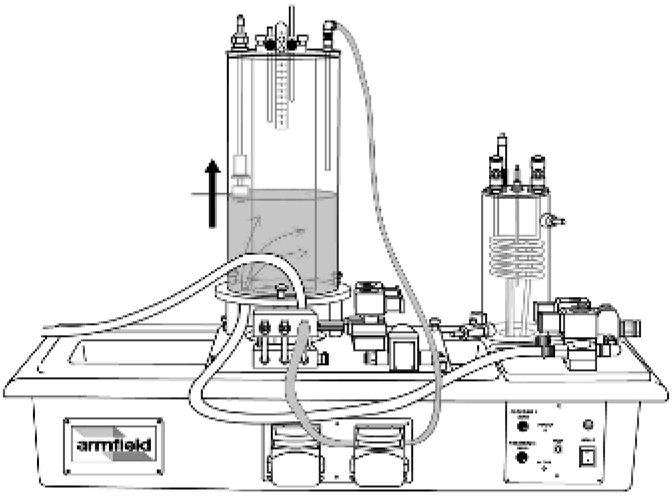




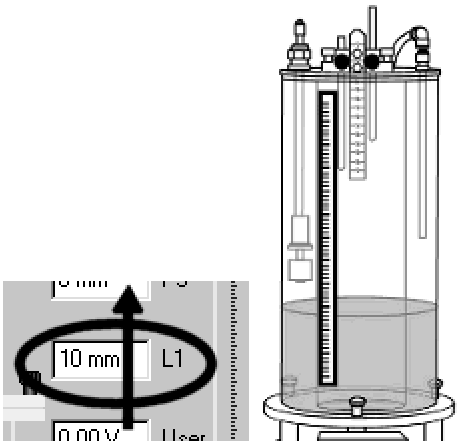
27. Open valve SOL1 by selecting the ‘Control’ button, then setting Manual control at 100%.



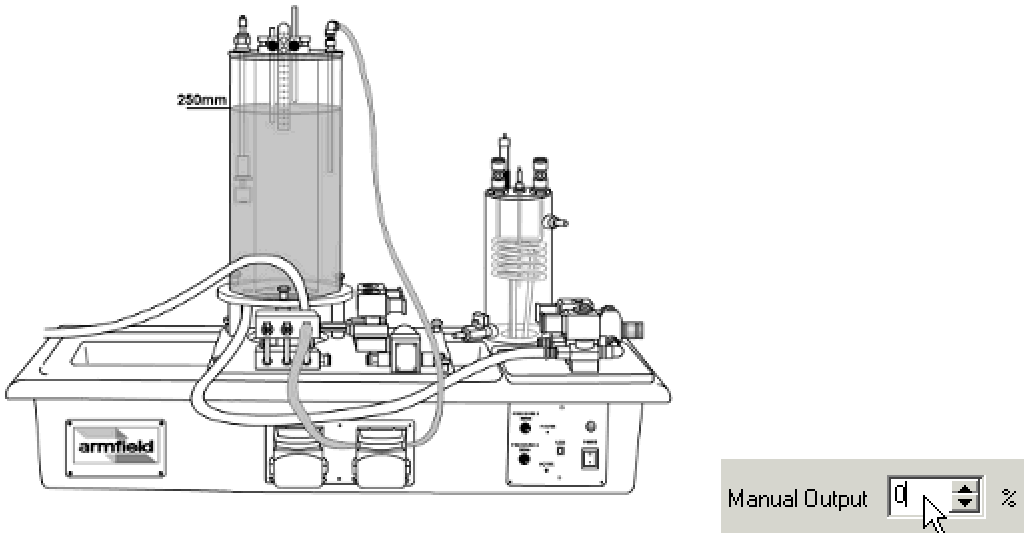
28. The large process vessel will begin to fill with water.



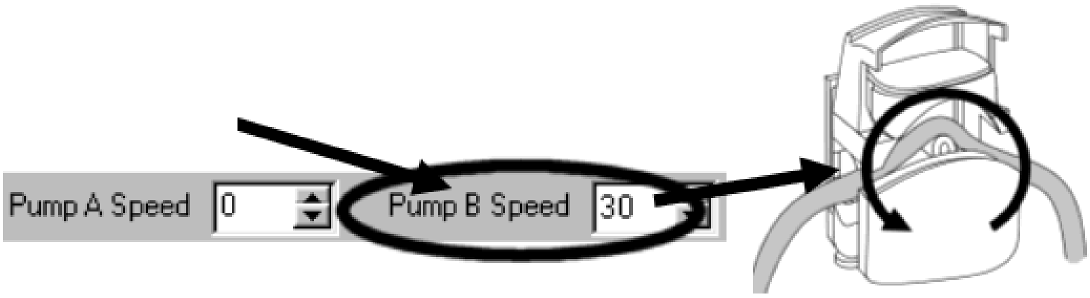
29. Observe that the level sensor reading on the software screen increases as the water level rises. The sensor output should approximately match the level reading from the gauge on the vessel side (the calibration procedure for the sensor is described in the PCT40 software Help Text).



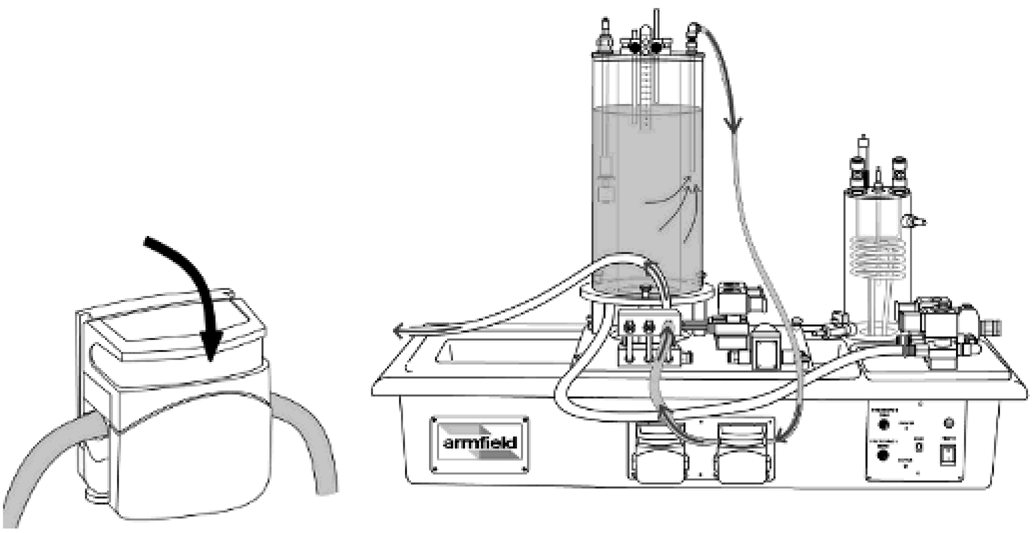
30. Allow the water in the large process vessel to reach a level of 250mm, then close the valve SOL1 by setting it back to 0%.



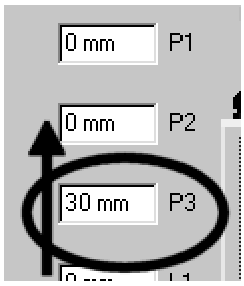
31. With the lid of the pump still open, set the speed of the pump to 30% by typing this value into the display box on the software screen. The pump should begin to operate.



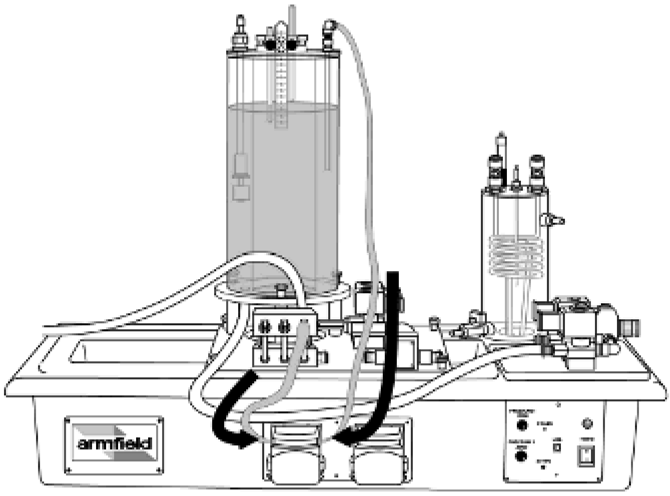
32. With the pump running, close the pump lid. Water should now be drawn along the tube from the large process vessel, through the pump and then through the differential pressure sensor set within the manifold block (in front of the large process vessel).



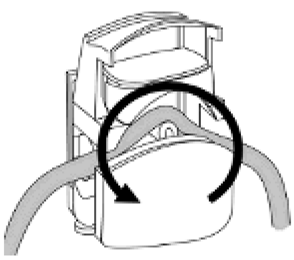
33. Check that there is a positive reading from the differential pressure sensor P3. Increase the speed of Pump B, and check that the differential pressure reading also increases. Reduce the speed of Pump A to 0.



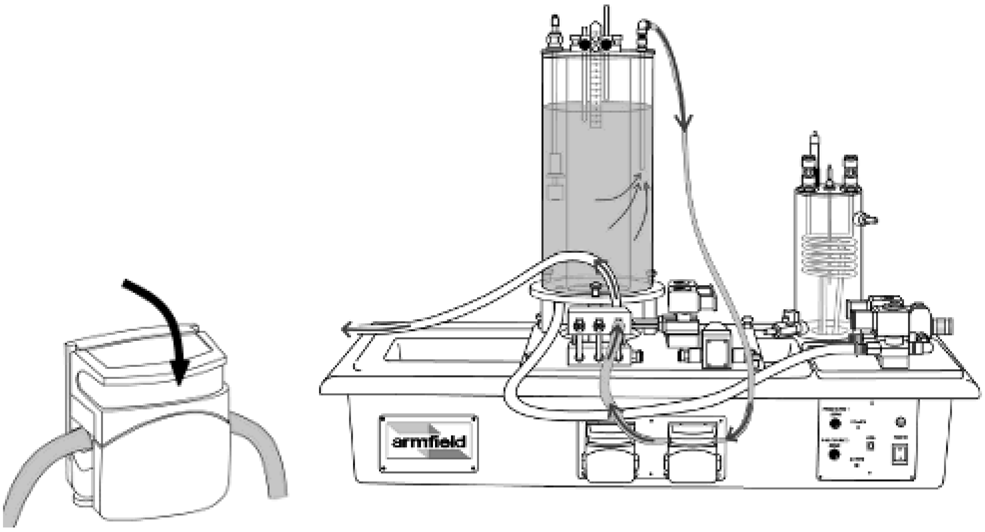
34. Open pump B, remove the tube, and transfer the tube to Pump A.



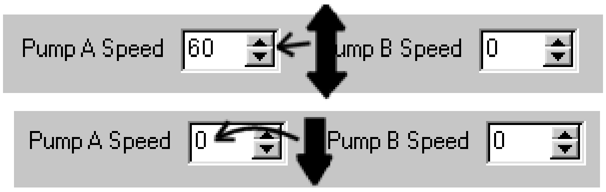
35. With Pump A open, set the speed of the pump to 30%. The pump should begin to operate.



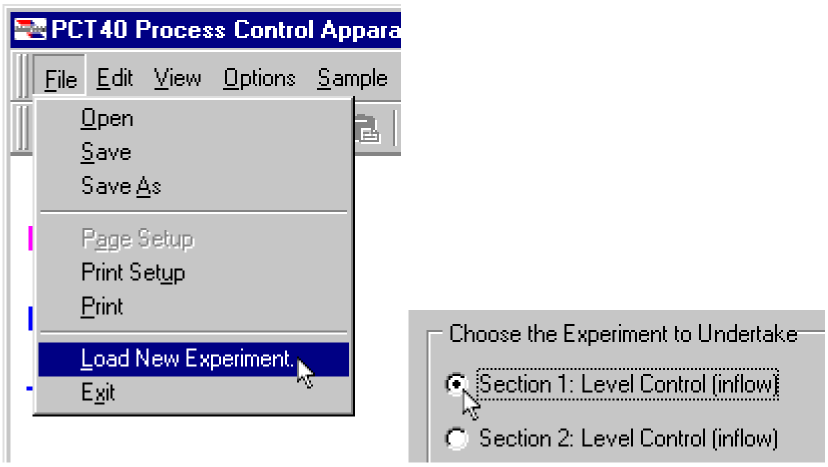
36. Close the pump lid. Water should now be drawn along the flexible tubing from the large process vessel, through Pump A and the differential pressure sensor then out to drain.



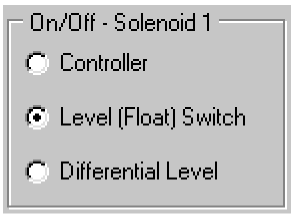
37. Vary the pump speed using the arrow keys to check that the pump is controlling correctly, then set the pump speed back to 0%.



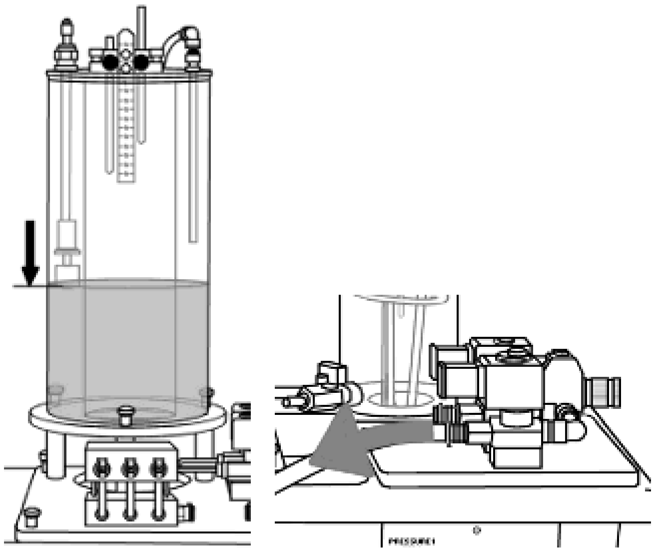
38. Select ‘Load New Experiment...’ from the ‘File’ menu, and load Exercise 1.



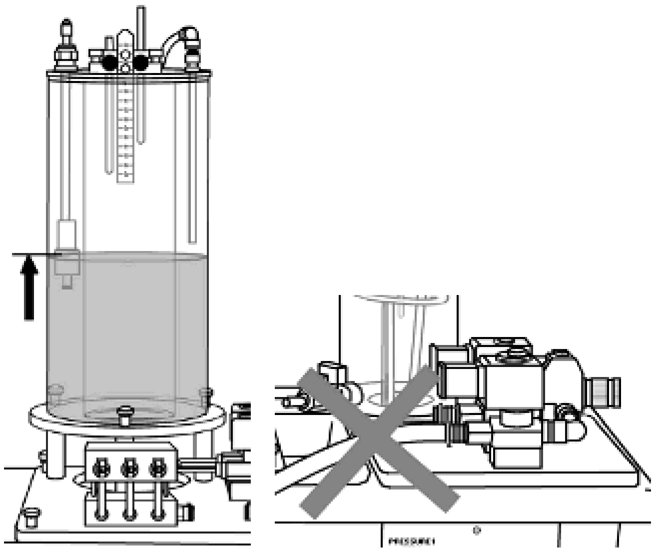
39. Set the software to control the valve SOL 1 using the Level (Float) Switch.



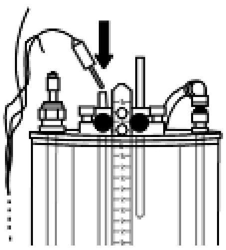
SOL1 should open when the water level in the tank drops so that the float reaches its lowest position...



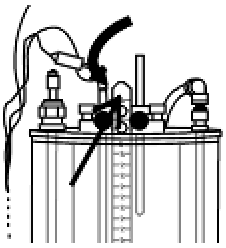
...and close when the float reaches the highest position as the water level rises once more.



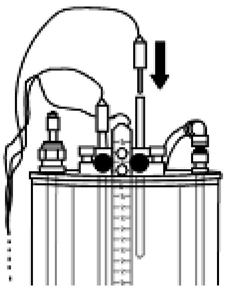
40. The blue plug (blue wire) to the top of the left-hand rod on the differential level switch, which should be positioned to give the low level setpoint.



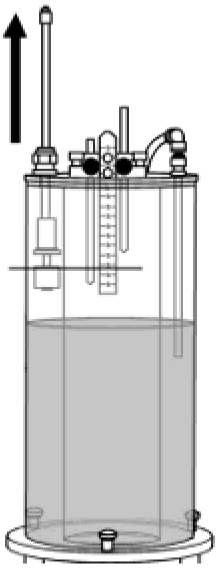
The green plug (green and yellow wire) to the socket on the back of the differential level switch (the connection behind the metal ruler).



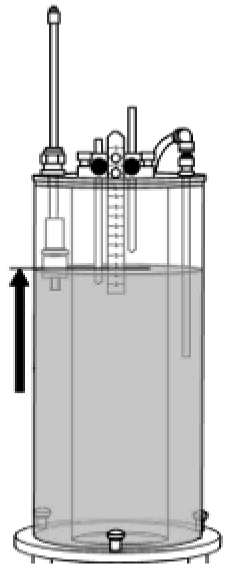
The red plug (brown wire) to the top of the right-hand rod on the differential level switch, which should be positioned to give the high level setpoint.



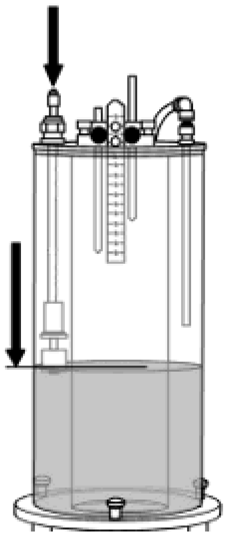
41. Adjust the level switch (float switch) until the float is higher than the lower of the two electrodes on the differential level switch.



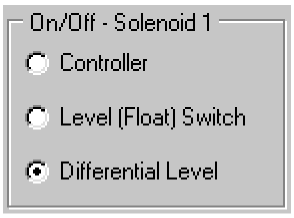
42. Allow the water level to reach the lower electrode on the differential level switch.



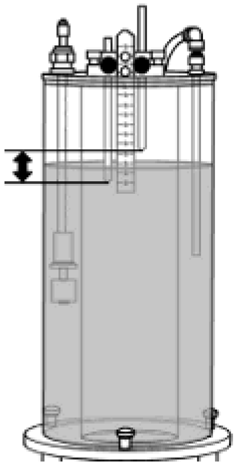
43. Lower the level switch and allow the water level in the vessel to drop to 50mm below the level of the differential level sensor.



44. Set the software to control the valve SOL1 using the Differential Level Switch.



The level in the tank should now be controlled by the differential level switch. SOL 1 should remain open until the water level in the tank reaches the higher of the two electrodes, then close until the water level reaches the lower of the two electrodes.



45. Switch the control of SOL 1 to ‘Controller’. The valve should

Your PCT40 Multifunction Process Control Unit is now installed, commissioned and ready for use. If the unit will not be used for some time, follow the procedure in Emptying Tubes with Self Sealing Ends to drain the equipment.

Ensure all users have read and understood the Important Safety Information section before operating the equipment.

Further information on the operation of the PCT40 may be found in the Operation section.

Electrical Wiring Diagram

Click on the relevant link to invoke the Wiring Diagram:

Wiring Diagram CDM29377/1

Wiring Diagram CDM29377/2

Printed Versions of this Instruction Manual

Please note, all wiring diagrams are appended at the rear of this manual

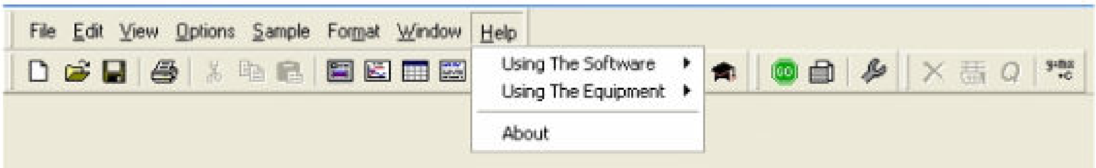
Operation

Where necessary, refer to the drawings in the Equipment Diagrams section.

Operating the Software

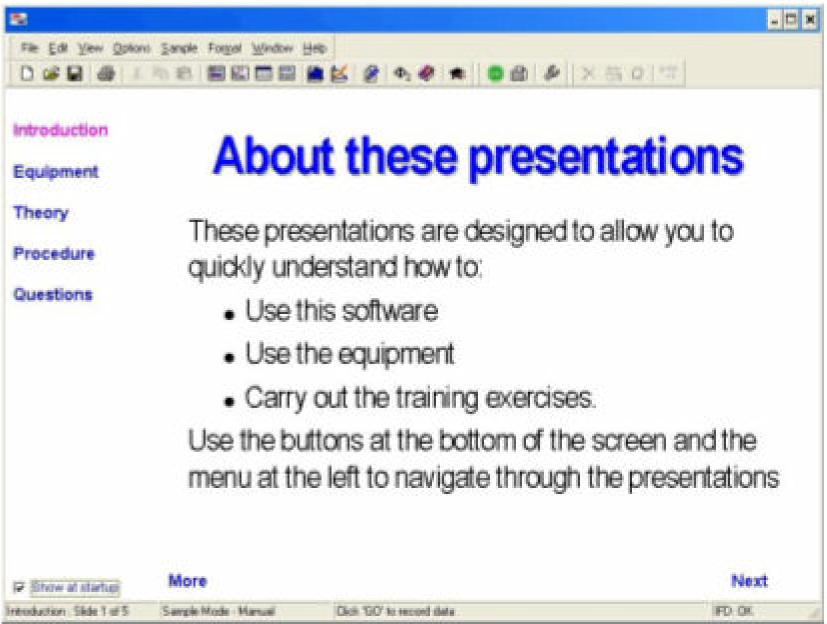
Note: The diagrams in this section are included as typical examples and may not relate specifically to the individual product described in this instruction manual.

The Armfield Software is a powerful Educational and Data Logging tool with a wide range of features. Some of the major features are highlighted below, to assist users, but full details on the software and how to use it are provided in the presentations and Help text incorporated in the Software. Help on Using the Software or Using the Equipment is available by clicking the appropriate topic in the **Help** drop-down menu from the upper toolbar when operating the software as shown:



Before operating the software ensure that the equipment has been connected to the IFD5 Interface (where IFD5 is separate from the equipment) and the IFD5 has been connected to a suitable PC using a USB lead. For further information on these actions refer to the Operation manual.

Load the software. If multiple experiments are available then a menu will be displayed listing the options. Wait for the presentation screen to open fully as shown:



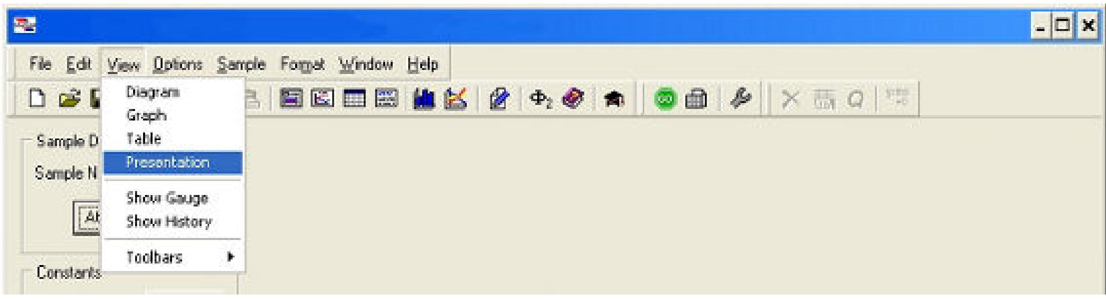
Before proceeding to operate the software ensure that **IFD: OK** is displayed at the bottom of the screen. If IFD:ERROR is displayed check the USB connection between the IFD5 and the PC and confirm that the red and green LED's are both illuminated. If the problem persists then check that the driver is installed correctly (refer to the Operation manual).

Presentation Screen - Basics and Navigation

As stated above, the software starts with the Presentation Screen displayed. The user is met by a simple presentation which gives them an overview of the capabilities of the equipment and software and explains in simple terms how to navigate around the software and summarizes the major facilities complete with direct links to detailed context sensitive 'help' texts.

To view the presentations click **Next** or click the required topic in the left hand pane as appropriate. Click **More** while displaying any of the topics to display a Help index related to that topic.

To return to the Presentation screen at any time click the View Presentation icon  from the main tool bar or click **Presentation** from the dropdown menu as shown:



For more detailed information about the presentations refer to the **Help** available via the upper toolbar when operating the software.

Toolbar

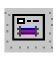
A toolbar is displayed at the top of the screen at all times, so users can jump immediately to the facility they require, as shown:

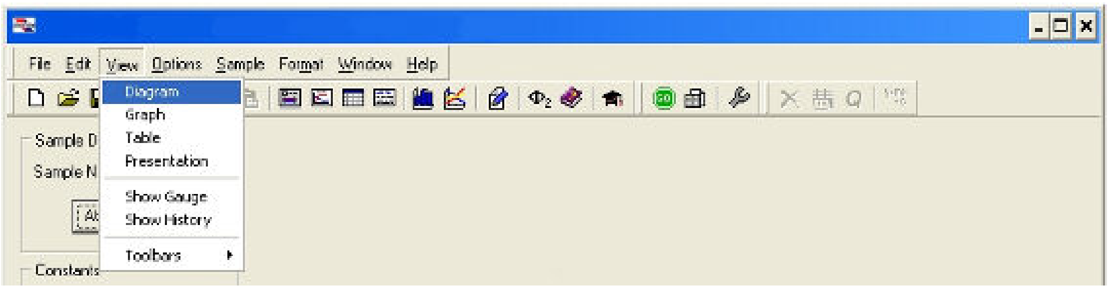
The upper menu expands as a dropdown menu when the cursor is placed over a name.

The lower row of icons (standard for all Armfield Software) allows a particular function to be selected. To aid recognition, pop-up text names appear when the cursor is placed over the icon.

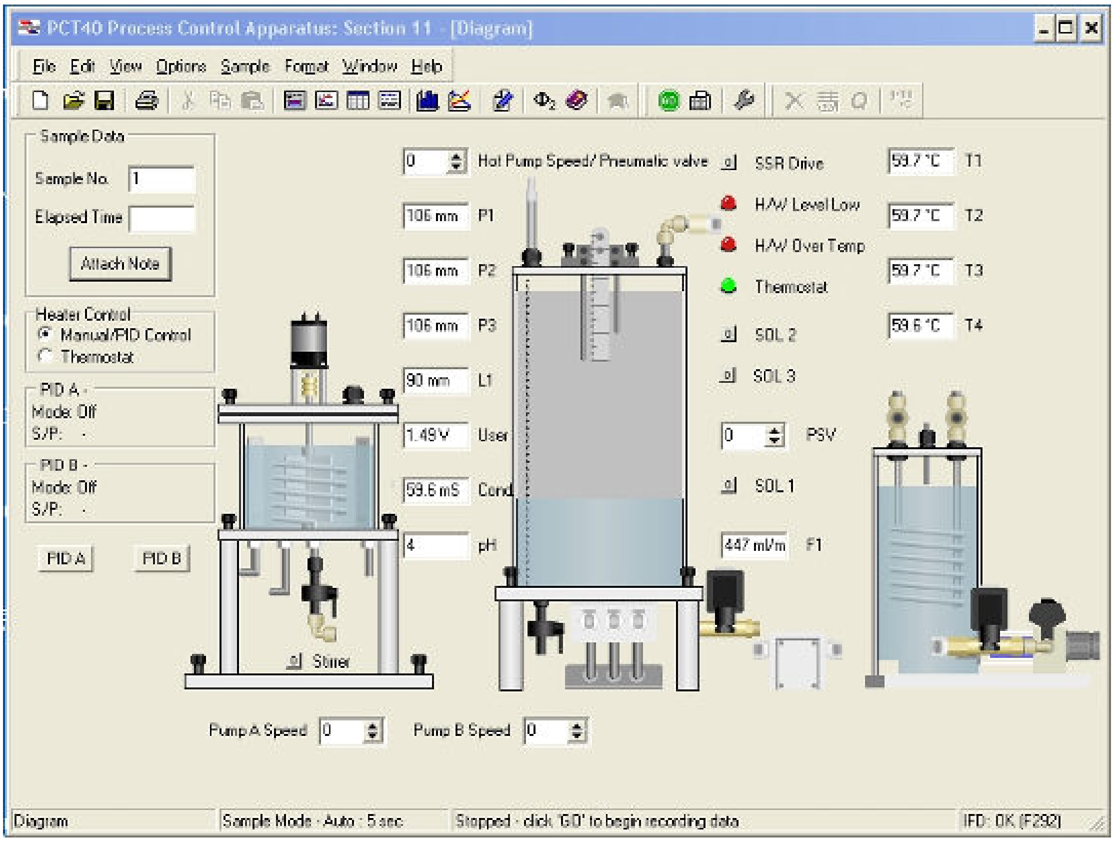
Mimic Diagram

The Mimic Diagram is the most commonly used screen and gives a pictorial representation of the equipment, with continuously updated display boxes for all the various sensor readings, calculated variables etc. directly in engineering units.

To view the Mimic Diagram click the View Diagram icon  from the main tool bar or click **Diagram** from the **View** drop-down menu as shown:



A Mimic diagram is displayed, similar to the diagram as shown:



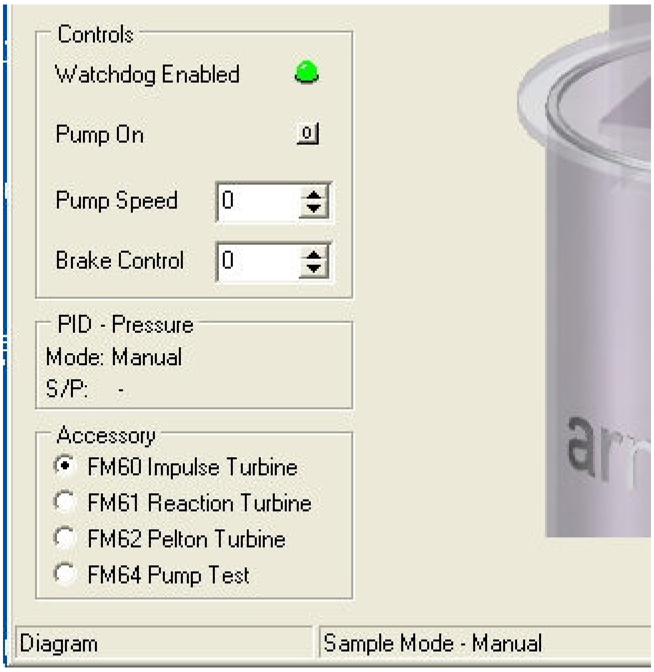
The details in the diagram will vary depending on the experiment chosen if multiple experiments are available.

In addition to measured variables such as Temperature, Pressure and Flowrate (from a direct reading flowmeter), calculated data such as Motor Torque, Motor Speed and Discharge / Volume flowrate (from pressure drop across an orifice plate) are continuously displayed in data boxes with a white background. These are automatically updated and cannot be changed by the user.

Manual data input boxes with a coloured background allow constants such as Orifice Cd and Atmospheric Pressure to be changed by over-typing the default value, if required.

The data boxes associated with some pressure sensors include a **Zero** button alongside. This button is used to compensate for any drift in the zero value, which is an inherent characteristic of pressure sensors. Pressing the **Zero** button just before starting a set of readings resets the zero measurement and allows accurate pressure measurements to be taken referenced to atmospheric pressure. This action must be carried out before the motor is switched on otherwise the pressure readings will be offset.

The mimic diagram associated with some products includes the facility to select different experiments or different accessories, usually on the left hand side of the screen, as shown:



Clicking on the appropriate accessory or exercise will change the associated mimic diagram, table, graphs etc to suit the exercise being performed.

Control Facilities in the Mimic Diagram

A **Power On** button allows the motor to be switched off or on as required. The button always defaults to off at startup. Clicking this button switches the power on (1) and off (0) alternately.

A box marked **Motor Setting** allows the speed of the motor to be varied from 0 to 100% either stepwise, by typing in values, or using the up / down arrows as appropriate. It is usual to operate the equipment with the motor initially set to 100%, then reduce the setting as required to investigate the effect of reduced speed on performance of the equipment.

When the software and hardware are functioning correctly together, the green LED marked **Watchdog Enabled** will alternate On and Off. If the Watchdog stops alternating then this indicates a loss of communication between the hardware and software that must be investigated.

Details on the operation of any automatic PID Control loops in the software are included later in this section.

Data Logging Facilities in the Mimic Diagram

There are two types of sampling available in the software, namely Automatic or Manual. In **Automatic logging**, samples are taken regularly at a preset but variable interval. In **Manual logging**, a single set of samples is taken only when requested by the operator (useful when conditions have to be changed and the equipment allowed to stabilize at a new condition before taking a set of readings).

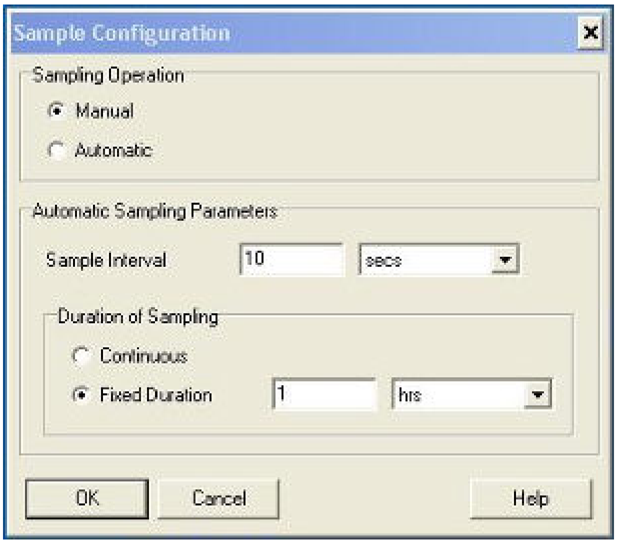
The type of logging will default to manual or automatic logging as appropriate to the type of product being operated.

Manual logging is selected when obtaining performance data from a machine where conditions need to stabilize after changing appropriate settings. To record a set of set of data values from each of the measurement sensors click the  icon from the main toolbar. One set of data will be recorded each time the  icon is clicked.

Automatic logging is selected when transients need to be recorded so that they can be plotted against time. Click the  icon from the toolbar to start recording, click the  icon from the toolbar to stop recording.

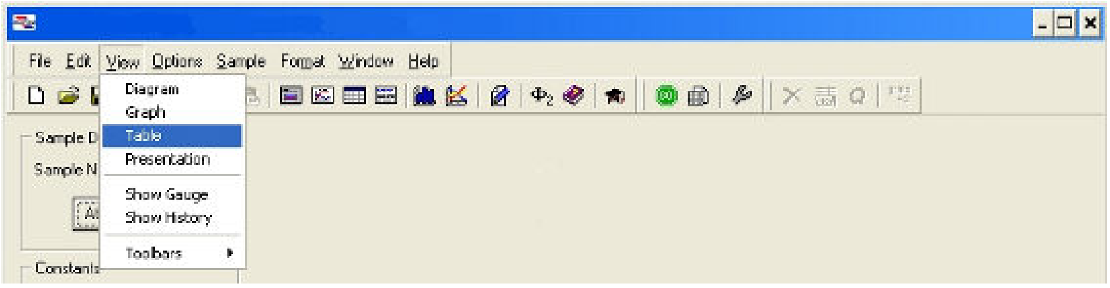
The type of logging can be configured by clicking **Configure** in the **Sample** drop-down menu from the upper toolbar as shown:

In addition to the choice of Manual or Automatic sampling, the parameters for Automatic sampling can also be set. Namely, the time interval between samples can be set to the required number of minutes or seconds. Continuous sampling can be selected, with no time limit or sampling for a fixed duration can be set to the required number of hours, minutes or seconds as shown:

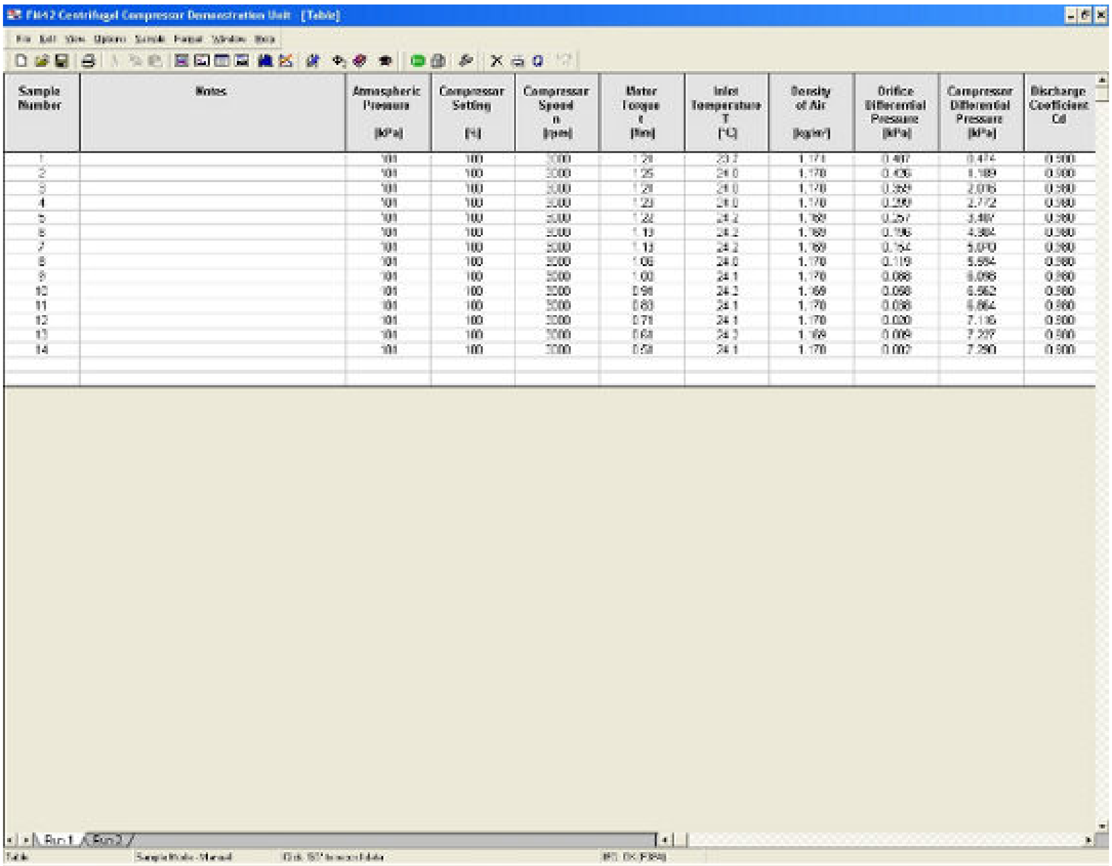


Tabular Display

To view the Table screen click the View Table icon  from the main tool bar or click Table from the View dropdown menu as shown:

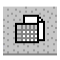


The data is displayed in a tabular format, similar to the screen as shown:



Sample Number	Notes	Atmospheric Pressure [kPa]	Compressor Setting [%]	Compressor Speed n [rpm]	Motor Torque t [Nm]	Inlet Temperature T [°C]	Density of Air [kg/m³]	Orifice Differential Pressure [kPa]	Compressor Differential Pressure [kPa]	Discharge Coefficient Cd
1		101	100	3000	1.28	23.7	1.171	0.487	0.474	0.980
2		101	100	3000	1.25	24.0	1.170	0.436	1.189	0.980
3		101	100	3000	1.28	24.0	1.170	0.364	2.016	0.980
4		101	100	3000	1.23	24.0	1.170	0.299	2.772	0.980
5		101	100	3000	1.22	24.2	1.169	0.257	3.487	0.980
6		101	100	3000	1.19	24.2	1.169	0.196	4.384	0.980
7		101	100	3000	1.13	24.2	1.169	0.154	5.070	0.980
8		101	100	3000	1.06	24.0	1.170	0.119	5.594	0.980
9		101	100	3000	1.00	24.1	1.170	0.088	6.096	0.980
10		101	100	3000	0.98	24.2	1.169	0.058	6.562	0.980
11		101	100	3000	0.80	24.1	1.170	0.038	6.864	0.980
12		101	100	3000	0.71	24.1	1.170	0.020	7.116	0.980
13		101	100	3000	0.64	24.3	1.169	0.009	7.277	0.980
14		101	100	3000	0.58	24.1	1.170	0.002	7.290	0.980

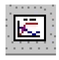
As the data is sampled, it is stored in spreadsheet format, updated each time the data is sampled. The table also contains columns for the calculated values.

New sheets can be added to the spreadsheet for different data runs by clicking the  icon from the main toolbar. Sheets can be renamed by double clicking on the sheet name at the bottom left corner of the screen (initially Run 1, Run 2 etc) then entering the required name.

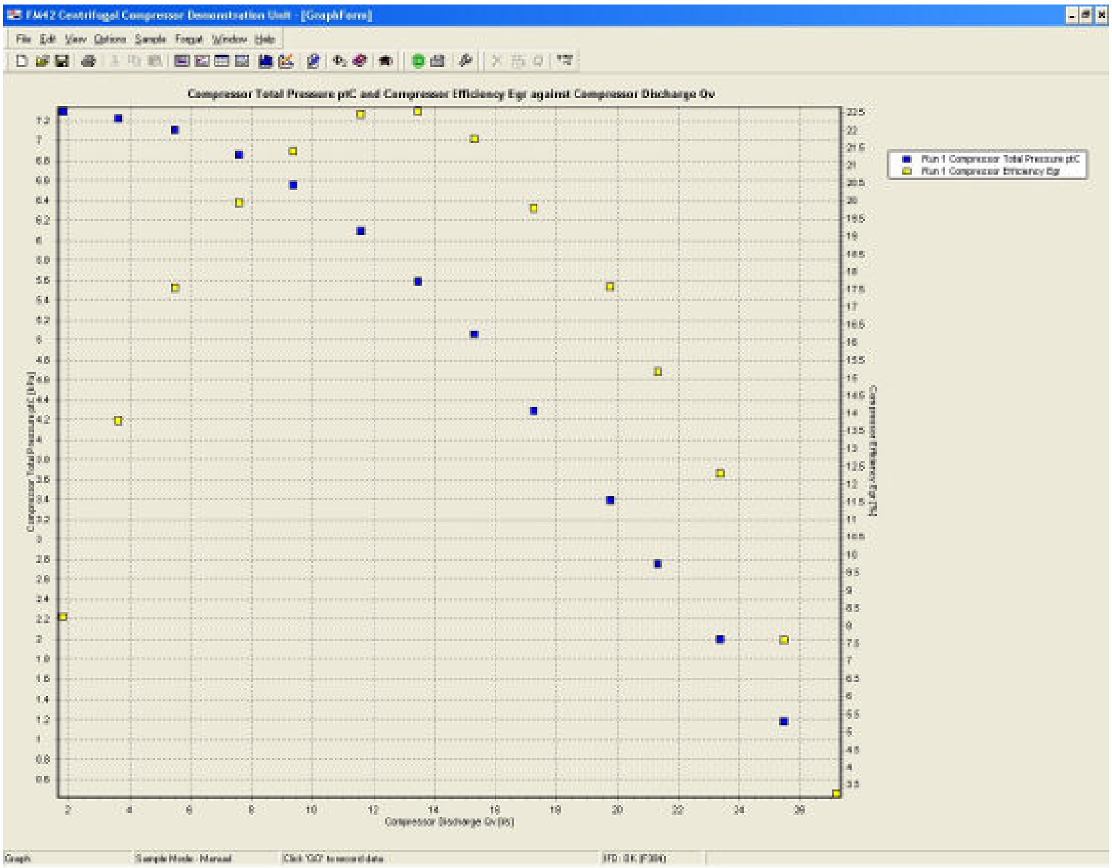
For more detailed information about Data Logging and changing the settings within the software refer to the **Help** available via the upper toolbar when operating the software.

Graphical Display

When several samples have been recorded, they can be viewed in graphical format.

To view the data in Graphical format click the View graph icon  from the main tool bar or click **Graph** from the **View** drop-down menu as shown:

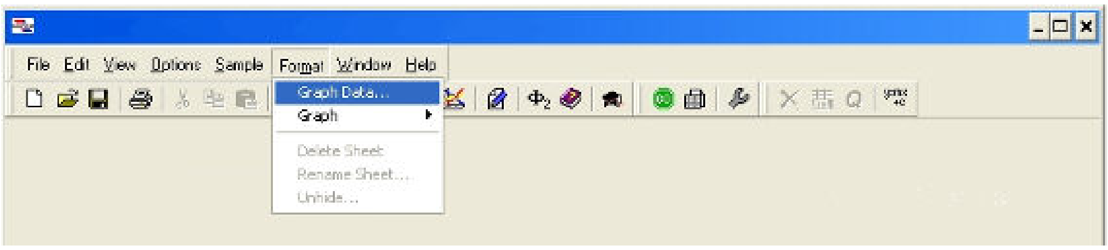
The results are displayed in a graphical format as shown:



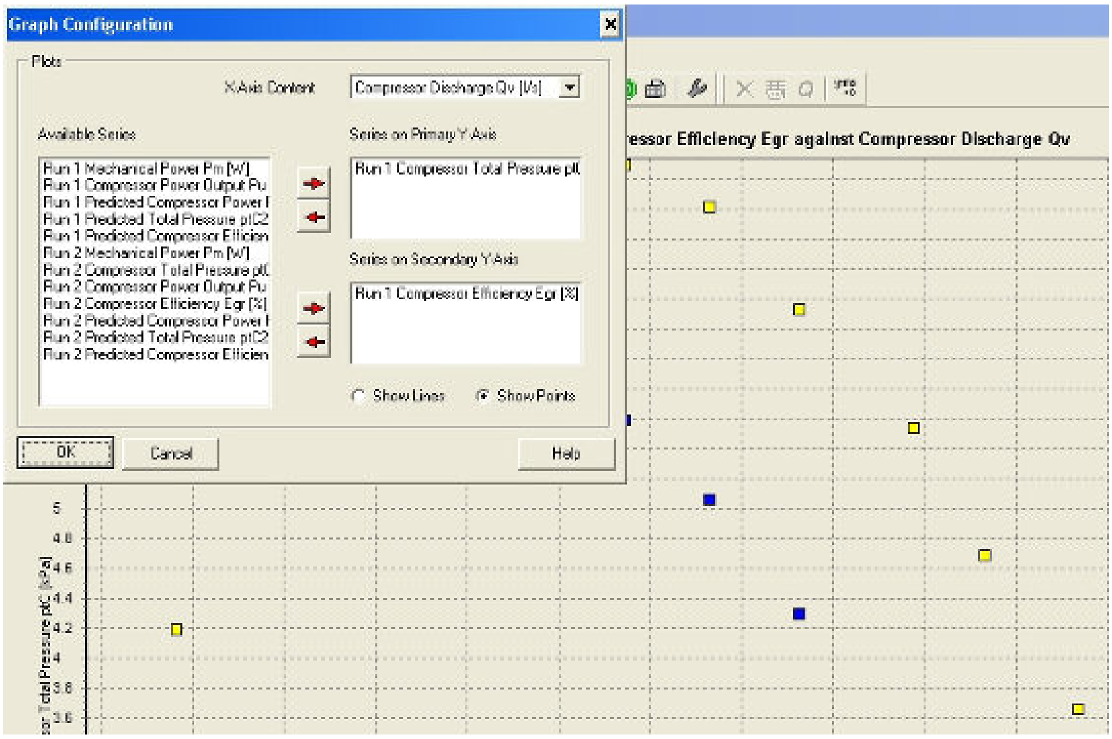
(The actual graph displayed will depend on the product selected and the exercise that is being conducted, the data that has been logged and the parameter(s) that has been selected).

Powerful and flexible graph plotting tools are available in the software, allowing the user full choice over what is displayed, including dual y axes, points or lines, displaying data from different runs, etc. Formatting and scaling is done automatically by default, but can be changed manually if required.

To change the data displayed on the Graph click **Graph Data** from the **Format** dropdown menu as shown:



The available parameters (Series of data) are displayed in the left hand pane as shown:



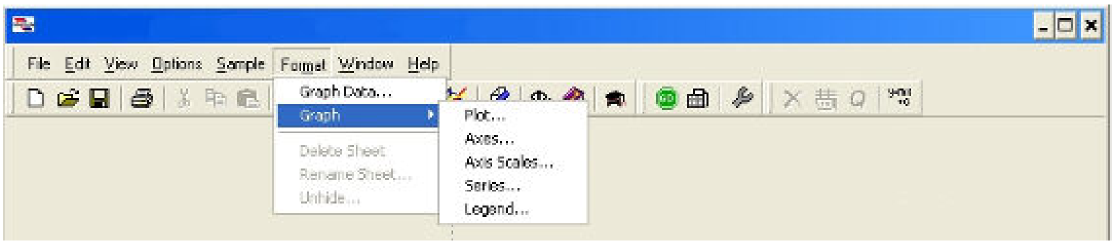
Two axes are available for plotting, allowing series with different scaling to be presented on the same x axis.

To select a series for plotting, click the appropriate series in the left pane so that it is highlighted then click the appropriate right-facing arrow to move the series into one of the windows in the right hand pane. Multiple series with the same scaling can be plotted simultaneously by moving them all into the same window in the right pane.

To remove a series from the graph, click the appropriate series in the right pane so that it is highlighted then click the appropriate left-facing arrow to move the series into the left pane.

The X-Axis Content is chosen by default to suit the exercise. The content can be changed if appropriate by opening the drop down menu at the top of the window.

The format of the graphs, scaling of the axes etc. can be changed if required by clicking **Graph** in the **Format** drop-down menu as shown:

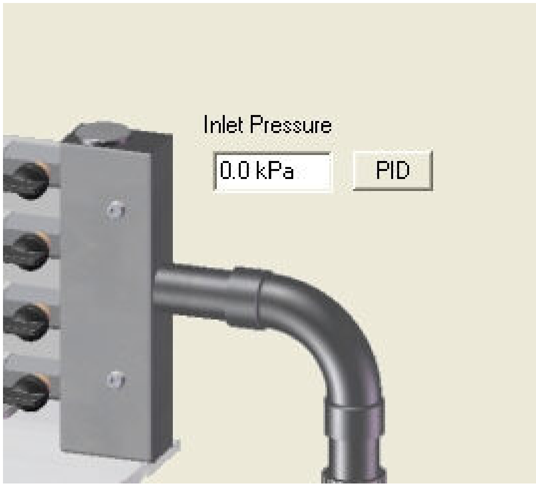


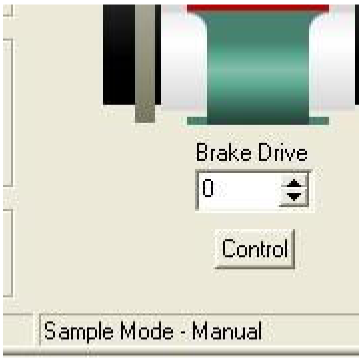
For more detailed information about changing these settings refer to the **Help** available via the upper toolbar when operating the software.

PID Control

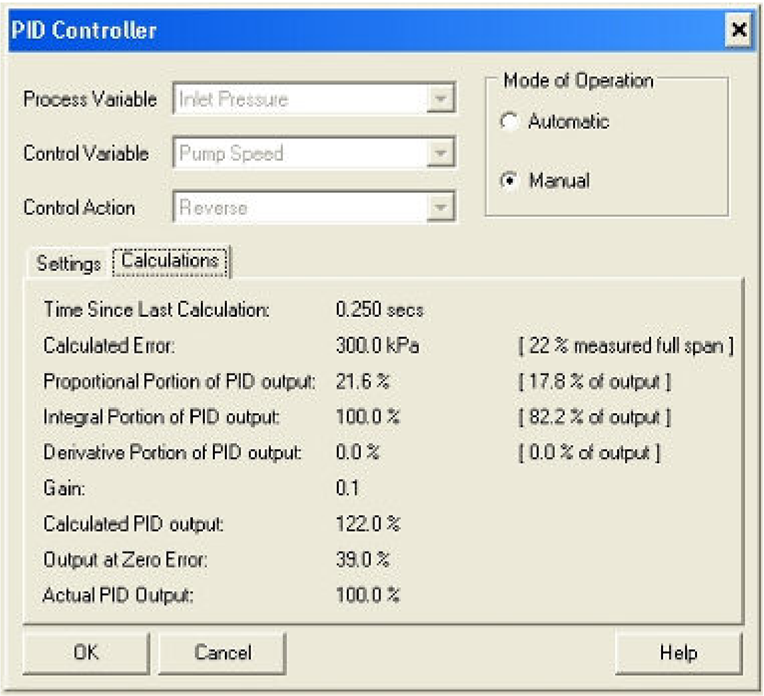
Where appropriate, the software associated with some products will include a single or multiple PID control loops whereby a function on the product can be manually or automatically controlled using the PC by measuring an appropriate variable and varying a function such as a heater power or pump speed.

The PID loop can be accessed by clicking the box labelled **PID** or **Control** depending on the particular software:





A PID screen is then displayed as shown:



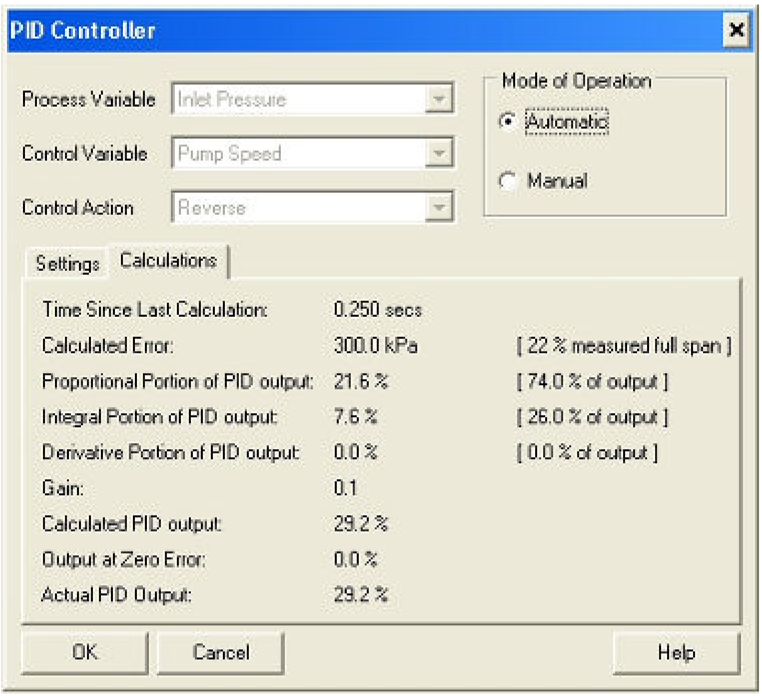
The Mode of operation always defaults to **Manual** control and 0% output when the software is loaded to ensure safe operation of the equipment. If appropriate, the operator can retain manual operation and simply vary the value from 0 to 100% in the **Manual Output** box, then clicking **Apply**.

Alternatively, the PID loop can be changed to Automatic operation by clicking the **Automatic** button. If any of the PID settings need to be changed from the default values then these should be adjusted individually before clicking the **Apply** button.

The controller can be restored to manual operation at any time by clicking the **Manual** button. The value in the **Manual Output** box can be changed as required before clicking the **Apply** button.

Settings associated with Automatic Operation such as the **Setpoint, Proportional Band, Integral Time, Derivative Time** and **Cycle Time** (if appropriate) can be changed by the operator as required before clicking the **Apply** button.

Clicking **Calculations** displays the calculations associated with the PID loop to aid understanding and optimization of the loop when changing settings as shown:



Clicking **Settings** returns the screen to the PID settings.

Clicking **OK** closes the PID screen but leaves the loop running in the background.

In some instances the **Process Variable, Control variable** and **Control Action** can be varied to suit different exercises, however, in most instances these boxes are locked to suit a particular exercise. Where the variables can be changed the options available can be selected via a drop-down menu.

Advanced Features

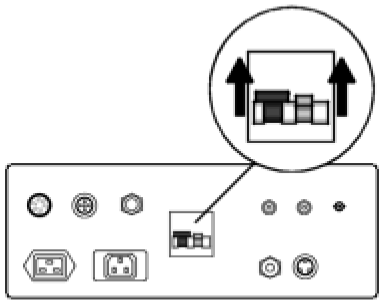
The software incorporates advanced features such as the facility to recalibrate the sensor inputs from within the software without resorting to electrical adjustments of the hardware. For more detailed information about these advanced functions within the software refer to the **Help** available via the upper toolbar when operating the software.

Operating the Equipment

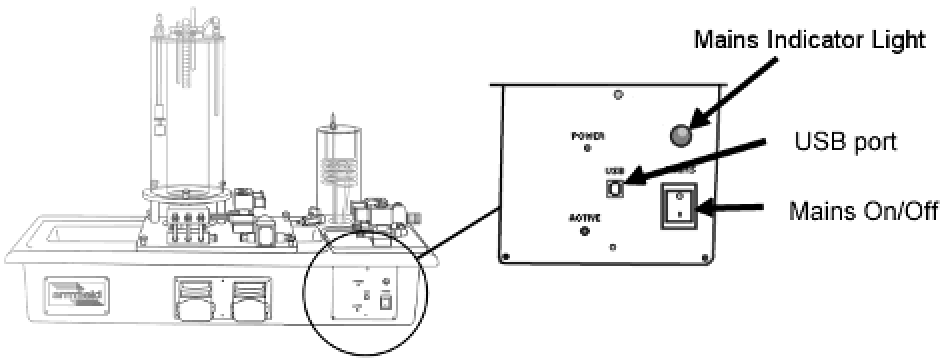
Note: Before operating the equipment ensure that it has been correctly installed in accordance with the Installation Process, and that you have read the Important Safety Information at the beginning of this manual.

Switching On

Before operating the apparatus, check that the RCD and circuit breakers at the back of the equipment are in the ON (up) position:



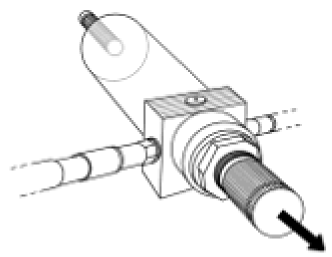
The on/off switch for the apparatus is located on the orange panel on the front of the plinth.



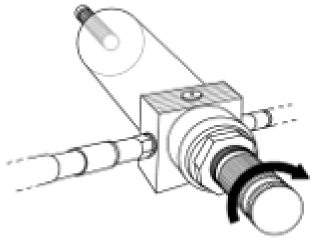
NOTE: The red and green LCD indicators on the front of the plinth are associated with the USB connection to the PC. These may be lit even if the PCT40 unit itself is switched off.

Setting the Pressure Regulator

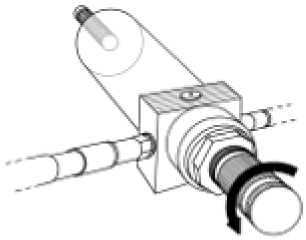
Before adjusting the flow rate through the pressure regulator, pull out the grey knob on the right hand side of the regulator (when looking at the plinth from the front):



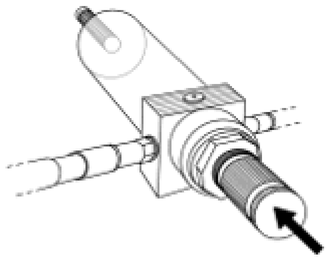
To increase flow through the pressure regulator, turn the knob slowly in a clockwise direction (looking at end of knob). The flow rate is measured by a flow meter downstream of the pressure regulator, and is indicated in L/min on the PCT40 software screen. Flow through the pressure regulator should not be taken above 1.5 L/min as this is the measurement limit of the flow meter. A maximum of 1.4 L/min is recommended.



To reduce the flow rate through the pressure regulator, turn the knob slowly in an anticlockwise direction (looking at end of knob):

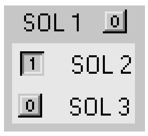


Once the appropriate flow rate is achieved, lock the regulator setting by pushing the grey knob back towards the body of the regulator:



Operating the On/Off Solenoid Valves

There are three On/Off Solenoid Valves on the base unit. SOL1 is located near the mains water inlet. SOL2 and SOL3 are located near the base of the large process vessel. When required for a teaching exercise, the valves are operated from the mimic diagram screen in the PCT40 software. The switches are represented as buttons on the screen, and are operated by clicking on them with the cursor. The switches will display a ‘0’ when the valves are off (closed) and a ‘1’ when the valves are on (open).



Some exercises include PID control of one solenoid valve. In these exercises the valve is controlled via the PID control window, and the switch is displayed onscreen only to give an indication of whether the switch is in the on or off position.

Operating the Proportioning Solenoid Valve

The Proportioning Solenoid Valve, PSV, is located near the mains water inlet. When required for the teaching exercise being undertaken, this valve is operated from the mimic diagram screen in the PCT40 software. The controls for the valve are represented by a text display box showing the current setting of the valve as a percentage value. For exercises requiring manual control of the PSV valve a second display box will include arrow buttons to increase (up arrow) the value or to decrease (down arrow) the value. New values may also be typed into this second box.

Some exercises include PID control of the proportioning solenoid valve. In these exercises the valve is controlled via the PID control window, and the control boxes are displayed onscreen only to give an indication of the valve position and (where applicable) the current manual setting.

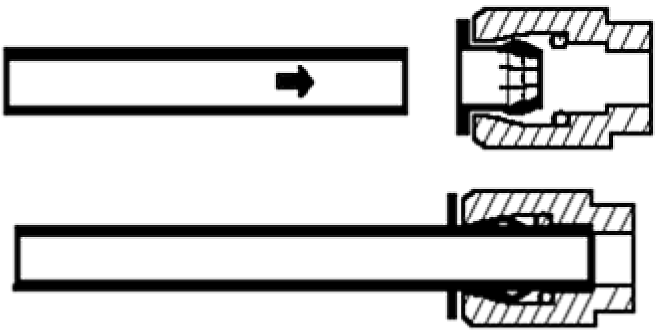
Filling the Process Vessels

The process vessels may if required be filled manually by removing the lid and pouring water in from the top. The large process vessel may also be filled via the tappings in the base from the mains inlet pipe. The small process vessel may be filled from the mains inlet pipe via one of the quick release fittings in the side wall. These may be connected to solenoid valve 1 (SOL1) or the Proportioning Solenoid Valve (PSV), and the valve may then be used to regulate flow from the mains inlet into the process vessel.

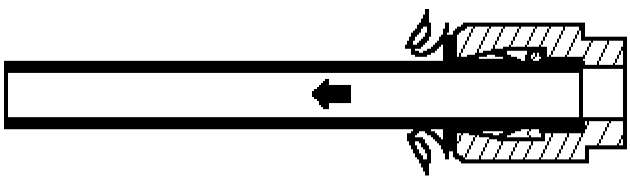
The teaching exercises provided in this manual include instructions for filling the vessel(s) as required.

Using the Guest Push Fittings

Tubes that may be connected to a Guest push fitting require a corresponding rigid tube coupling on the end of the tube. Align the parallel section of the rigid tube with the loose collet on the Guest push fitting and push firmly until the tube stops.

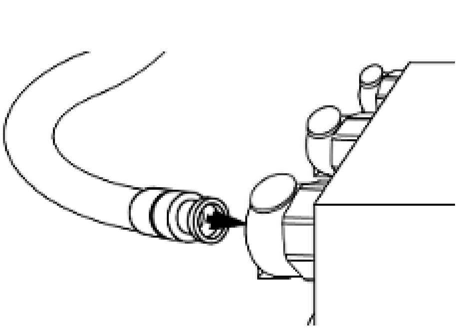


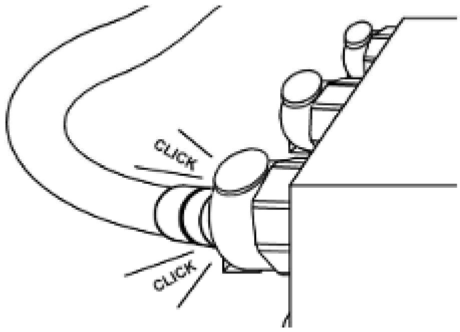
To remove the tube, push the loose circular collet against the body of the Guest push fitting while pulling the tube firmly. The tube will slide out from the fitting. The tube/fitting can be assembled and disassembled repeatedly without damage.



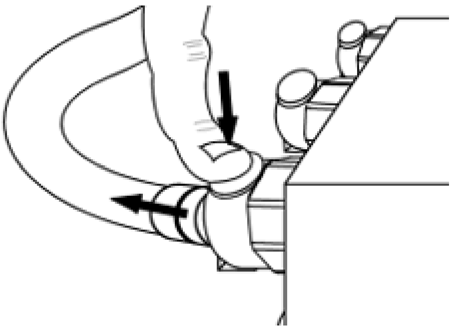
Using the Quick Release Fittings

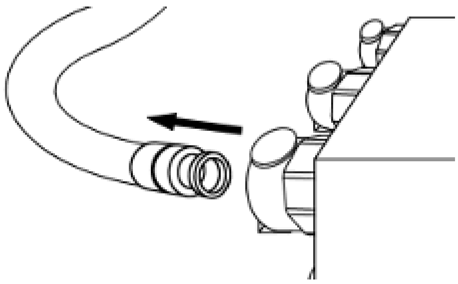
Tubes to be attached to one of the quick release sockets require a corresponding male coupling on the end of the tube. To connect a tube, push the end of the tube into the socket until an audible click is heard.





To remove a tube, press the metal catch against the socket and pull the tube free.

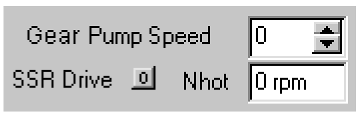




Where appropriate, some quick release fittings incorporate a self-sealing valve to prevent loss of fluid when the fitting is disconnected.

Controlling the Gear Pump

When required for a teaching exercise, the gear pump is controlled from the mimic diagram screen in the PCT40 software. The pump setting is displayed as a percentage value and a value in revolutions per minute. The required setting may be typed directly into the percentage display box, or adjusted up or down using the arrow keys attached to the box.



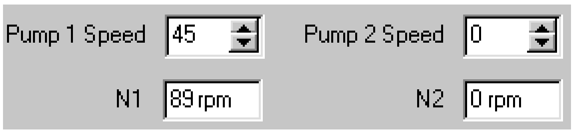
Some exercises include PID control of the gear pump. In these exercises the pump is controlled via the PID control window, and the control boxes are displayed onscreen only to give an indication of the pump speed and (where applicable) the current manual setting.

Using the Peristaltic Pumps

To insert flexible tubing into the pump head:

Raise the cover on the pump head. Adjust the knurled screw at each side until the indicator aligns with the tube size is indicated (6.3 mm inside diameter in the case of PCT40). Lay the tube over the rollers then carefully close the pump head ensuring that the tubing is not trapped and is located centrally in the vee at each side. Not that only the silicon tubing with 1.6 mm wall thickness can be used in the peristaltic pumps.

For teaching exercises that use the peristaltic pumps, the pumps are controlled from the mimic diagram screen in the PCT40 software. The pump settings are displayed as percentage values and a value in revolutions per minute. The required settings may be typed directly into the percentage display box, or adjusted up or down using the arrow keys attached to the boxes. A fault light is also displayed in the software, which will light if a fault is detected with the pump.



Some exercises include PID control of one peristaltic pump. In these exercises the pump is controlled via the PID control window, and the control boxes are displayed onscreen only to give an indication of the valve position and (where applicable) the current manual setting.

Operating the Heating Element

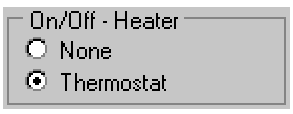
The heating element operates on a simple On/Off switch. When required for a particular teaching exercise it is controlled from the mimic diagram screen in the PCT40 software. The switch is represented as a button on the screen, and is operated by clicking on it with the cursor. The switch will display a ‘0’ when the heating element is off and a ‘1’ when the element is on.

Some exercises include PID control of the heater. In these exercises the heater is controlled via the PID control window, and the switch is displayed onscreen only to give an indication of whether the heater is on or off.

The heating element may also be controlled using the thermostat mounted on the lid of the small process vessel, as described below.

Use of the Thermostat (Temperature Switch)

A thermostat is mounted on the lid of the small process vessel. In some exercises, the heating element is controlled using this thermostat. The thermostat switches the heater on when the temperature in the vessel is below a Set Point value, and off when the temperature is above that value. The Set Point may be selected using the circular selector on top of the thermostat. Thermostat control may be selected in the software by selecting the Thermostat radio button on the mimic diagram screen of the software:



Use of the Differential Pressure Sensors

When required, the outputs from the differential pressure sensors are displayed on the mimic diagram screen in the PCT40 software. The pressure sensors are located inside the manifold block in front of the large process vessel, and each is used in conjunction with an orifice within the block. P1 and P2 are only used for small flowrates associated with PCT41. To direct flow through the large orifice / P3, connect the outlet flow from the peristaltic pump to the self-sealing fitting front of the manifold block, as described in the appropriate teaching exercise. Connect another tube to the Guest push fitting on the back of the manifold and direct the outlet flow as required for the exercise. The internal pressure sensor will then provide the differential pressure between the opposite sides of the orifice. Note that the downstream connection from the orifice to P3 incorporates an in-line quick release connector. In normal use this is connected to give differential pressure that is related to flow. Alternatively the connection can be broken, with the sensor vented to atmosphere to allow line pressure to be measured. In some exercises, the second pump is connected to the upstream side of the orifice using the connector on the right hand end of the block.

Emptying tubes with self-sealing ends

Some of the tubes supplied with the equipment have self-sealing ends. This prevents any fluid from draining out of the apparatus when changing the configuration of the plumbing. However, it also prevents water draining naturally from the tubing when the tubing is not in use. It is therefore recommended that the tubing be manually drained if the equipment is not to be used for some time, to prevent any possibility of harmful micro-organisms building up inside the trapped water.

Self-sealing fittings may be manually drained as follows:

Hold both ends of the tubing over a suitable sink or drain.

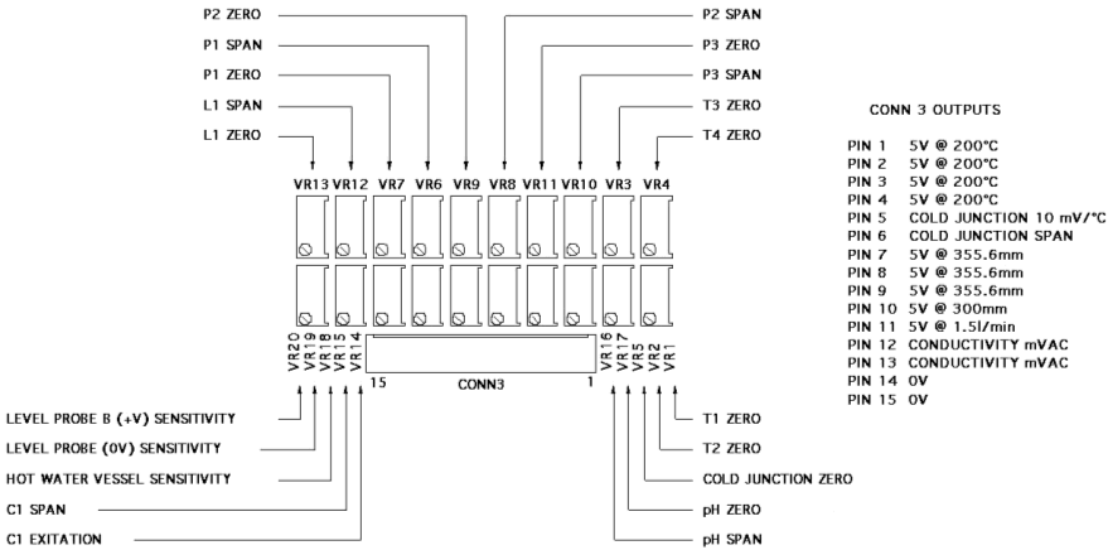
Depress the ends of both self-sealing fittings, taking care not to completely block the ends, allowing water to drain.

Tilt the tube until all the water has drained out.

The tubing can now safely be stored until needed.

Calibration of the sensor conditioning circuits

Zero and Span potentiometers for the sensor conditioning circuits are grouped together at the right hand end of the bottom moulded plinth section. These controls can be accessed by removing the small cover plate. The location of the potentiometers is shown on a diagram attached to the rear of the cover plate. The diagram is included below for information.



Note: The software supplied with the PCT40 includes the ability to recalibrate each of the sensors if necessary. Small changes in calibration should therefore be made using the software. Re-calibration using the potentiometers should not therefore be necessary unless a large change is required such as following the replacement of a sensor etc.

DAC Programming

A 12-bit DAC (Digital to Analogue Converter) Chip is used to control the Gear Pump and PSV on the PCT40.

The chip is model number LTC1456. A datasheet can be found on the Internet by entering the part number into a search engine such as Google.

The required output must first be coded into binary. The output can be from 0 to 4095.

All three lines should be set low (0). The most significant bit (MSB) should then be set on line 2, and then a clock pulse should be sent on line 1. This is repeated until the least significant bit (LSB) has been sent and clocked.

A load pulse should then be sent on line 3.

However, on PCT40, two chips are used in series, and so 24 bits must be sent before the load pulse. The first 12 bits will control the hot water pump, and the last 12 will control the solenoid valve.

Connections using flexible tubes

A set of flexible tubes is supplied with the PCT40. The tubes vary in material, length terminations etc and are used in different applications on PCT40. The tubes are listed below with a brief description and details of their application.

2 x 2.5m long flexible silicone rubber tube, 6.3mm bore, 1.6mm wall (Unsealed quick release fittings both ends). Used in peristaltic pumps A and B.

2 x 2m long flexible clear PVC tubes (90 degree Guest push fitting / plain end). Used to connect outlet of SOL2 and SOL3 to drain

2 x 1m long flexible clear PVC tubes (Sealed quick release fittings both ends). Used to connect between different vessels / control devices.

1 x 2m long flexible clear PVC tube (Guest push fitting / plain end). Used to connect T4 or P3 to drain.

1 x 1m long flexible clear PVC tube (Guest push fitting / unsealed quick release fitting). Used for connecting inlet of coil (T2) to control device E.g. SOL1.

1 x 2m long flexible clear PVC tube (Unsealed quick release fitting / Guest push fitting with flow control valve). Used to connect outlet of coil (T3) or small process vessel to drain with valve to vary flowrate when required.

1 x 1.5m long flexible clear PVC tube (9 mm ID, Plain end / plain end). Used to connect drain valve in moulded channel to drain

1 x 4m long flexible clear PVC tube (Unsealed quick release fitting / Guest push fitting). Used as a holding tube when connected between T3 and T4.

Equipment Specifications

Overall Dimensions

Height : 0.725 m

Width : 1.000 m (plinth)

Depth : 0.530 m (plinth plus pumps)

Electrical Supply

The equipment requires connection to a single phase, fused electrical supply.

Model	**PCT40-A**	**PCT40-B**	**PCT40-G**
GREEN/YELLOW	Earth (Ground)	Earth (Ground)	Earth (Ground)
BROWN	Live (Hot)	Live (Hot)	Live (Hot)
BLUE	Neutral	Neutral	Neutral (Hot)
Fuse Rating	10 AMP	20 A	10 A
Voltage	220-240V	110-120V	220V
Frequency	50 Hz	60 Hz	60 Hz

I/O Port Pin Connections

The 60 way I/O connector at the right-hand end of the moulded plinth carries the control signals to / from accessories such as the PCT43 Electronic Console. This connector can be used to connect other devices to the PCT40 if required for project work etc. The pin-outs on the connector are as follows:

Pin No	**Channel No**	**PCT43 Function**	**Signal**	**Eng Unit**
1	Channel 0	Temperature T1	0 – 5V	0 –200 ^{o}C
2	Channel 1	Temperature T2	0 – 5V	0 –200 ^{o}C
3	Channel 2	Temperature T3	0 – 5V	0 –200 ^{o}C
4	Channel 3	Temperature T4	0 – 5V	0 –200 ^{o}C
5	Channel 4	Pressure P1	0 – 5V	0 – 355.6 mm
6	Channel 5	Pressure P2	0 – 5V	0 – 355.6 mm
7	Channel 6	Pressure P3	0 – 5V	0 – 355.6 mm

8	Channel 7	Level L1	0 – 5V	0 – 300 mm
9	Channel 8	Flowrate F1	0 – 5V	0 – 1.5 l/min
10	Channel 9	USER INPUT	0 – 5V	-
11	Channel 10	Conductivity	0 – 5V	0 – 200 mS
12	Channel 11	pH	0 – 5V	0 – 14 pH
13	Channel 12	Not used		
14	Channel 13	Not used		
15	Channel 14	Not used		
16	+5V Out	+5V Supply		
17	Analog ground	0V		
18	Amp Lo	0V		
19	+12V Out	+12V Supply		
20	-12V Out	-12V Supply		
21	Power Ground	0V		
22	DAC0 Output	Pump A Speed	0 – 5V	RPM
23	DAC0 Ground	0V		
24	DAC1 Output	Pump B Speed	0 – 5V	RPM
25	DAC1 Ground	0V		
26	Digital Ground			
27	Digital Ground			
28	Digital Input Line 0	Not used		
29	Digital Input Line 1	Not used		
30	Digital Input Line 2	HW Vessel Low Level		
31	Digital Input Line 3	HW Vessel Over Temp		

32	Digital Ground	0V		
33	Digital Input Line 4	Thermostat on/off		
34	Digital Input Line 5	Level switch on/off		
35	Digital Input Line 6	Not used		
36	Digital Input Line 7	Diff Level Switch on/off		
37	Digital Ground	0V		
38	Digital Output Line 0	DAC-CLK (Hot water pump and PSV control)		
39	Digital Output Line 1	DAC-Din (Hot water pump and PSV control)		
40	Digital Output Line 2	DAC-CS/LD (Hot water pump and PSV control)		
41	Digital Output Line 3	SSR Drive		
42	Digital Ground			
43	Digital Output Line 4	Solenoid valve SOL1 on/off		
44	Digital Output Line 5	Solenoid valve SOL2 on/off		
45	Digital Output Line 6	Solenoid valve SOL3 on/off		
46	Digital Output Line 7	PCT41 Stirrer on/off		
47	Digital Ground	0V		
48	Aux Output 1	USB/PCT43 Control		
49	Aux Output 2	Gear Pump or PCT44 valve	0 – 5V	

50	Aux Output 3	PSV Control	0 – 5V	
51		+24V Supply		
52		+24V Supply		
53		+24V Supply		
54		0V		
55		0V		
56		0V		
57		+12V Supply		
58		+5V Supply		
59		-12V Supply		
60		0V		

Other Specifications

Temperature sensors T1 – T4	Type k, 0 – 200 °C
Pressure sensor L1	Piezo, 0 - 300 mm H2O (gauge)
Pressure sensors P1 – P3	Piezo, 0 - 355.6 mm (differential)
Turbine flowmeter	0.2 – 1.5 litres/min
Solenoid valve SOL1	Orifice 2.4 mm diameter
Solenoid valve SOL2	Orifice 2.4 mm diameter
Solenoid valve SOL3	Orifice 3.2 mm diameter
Proportioning Solenoid Valve	Orifice 2.4 mm diameter
Peristaltic Pump Flow rate (6.3 mm ID tube)	0 – 1.3 litres/min (nominal)
Large Process Vessel Capacity (Full)	6.8 litres (nominal)
Large Process Vessel Capacity (Reduced)	4 litres (nominal)

Heater power (small process vessel)	2 kW (nominal)
Maximum hot water temperature	80 ^{o}C (nominal)

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

a. Indoor use;

b. Altitude up to 2000 m;

c. Temperature 5 °C to 40 °C;

d. Maximum relative humidity 80 % for temperatures up to 31 °C, decreasing linearly to 50 % relative humidity at 40 °C;

e. Mains supply voltage fluctuations up to ±10 % of the nominal voltage;

f. Transient over-voltages typically present on the MAINS supply;

Note: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

Normally only nonconductive pollution occurs.

Temporary conductivity caused by condensation is to be expected.

Typical of an office or laboratory environment

Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

The equipment should be disconnected from the electrical supply when not in use.

The process vessels, optional reactor vessel, heating/cooling coil and pipework should be drained after use. Water pumped through the equipment will remove chemical deposits from the pumps, flowmeter, supply lines etc.

In areas of hard water, the amount of scale in the process vessels and pipework can be reduced by fitting a de-ioniser in-line with the water supply to the equipment.

After use, release the heads of the peristaltic pumps by pivoting the clamp on the pump head upwards and backwards to expose the rotor. This takes the pressure off the flexible tubing and will prolong the life of the tubing.

The life of the flexible tubing used in the peristaltic pump heads can be extended by moving the tubing through the pump head to an unused section at regular intervals.

When replacement of the flexible tubing is necessary it is important to ensure that the replacement tubing is compatible as follows:

PCT40 exercises

Altec code 01-93-1432

Material 'Altesil' High Strength Silicon Rubber

Wall thickness 1.6 mm

Inside diameter 6.3 mm

PCT41 exercises

Watson Marlow code 913.A032.016

Material Silicon Rubber

Wall thickness 1.6 mm

Inside diameter 3.2 mm

General connections on Process Plant Trainer

Material Clear PVC

Inside diameter 6 mm or 9 mm as appropriate

Note: Before attempting to replace the flexible tubing in either peristaltic pump head, ensure that the equipment has been switched off to prevent inadvertent rotation of the rollers.

Before installing the flexible tubing ensure that the adjusters on either side of the pump head (at the bottom) have been set to the diameter of tube in use. (The standard tubing supplied with PCT40 has a bore of 6.3 mm and the tubing supplied with PCT41 has a bore of 3.2 mm so the indicator must align with the 6.4 mark or the 3.2 mark as appropriate when the head is unclamped.) To install or replace the flexible tubing lift the clamp (on the top of the pump head) upwards and backwards to expose the rotor. Load the tubing into the slot between the rotor and pump head then close the pump head by pushing the clamp forwards and downwards. The clamp will click shut. The tube will retain its elasticity for many hours of use but there is sufficient length to allow the tube to be moved to other positions of less wear. It is essential to release the clamp when the equipment is not being used to prevent permanent deformation of the tube.

RCD Test

Test the RCD by pressing the TEST button at least once a month. If the RCD button does not trip when the Test button is pressed then the equipment must not be used and should be checked by a competent electrician.

Cleaning the Equipment

Build-up of scale on the inside of the process vessels can be minimised by drying the vessels when they are to be left unused for some time. Scale that does develop within the large process vessel may be cleaned by hand.

It will be necessary to clean the filter in the pressure regulator at regular intervals. If the filter is visibly obstructed or the inlet flow rate appears reduced then the filter may need cleaning. Remove the filter from the equipment and clean by flushing with clean water flowing in the opposite direction to normal flow. The frequency of cleaning will depend on the cleanliness of the water supply.

Any build up of scale in the pipe work or process vessels can be removed by passing a mild descaler through the system then flushing thoroughly with clean water. Any stubborn deposits in the large process vessel can be eliminated by manual cleaning. Remaining deposits in the smaller vessel may need longer soaking in descaling solution. Always follow the instructions provided with the descaler regarding suitable dilution of the chemical.

The water in both of the process vessels should be drained after use or at least changed at regular intervals to prevent the growth of algae that may present a hazard to health.

Accessing the electrical circuits inside the plinth

Maintenance of the PCT40 does not require access to the electrical circuits or components located inside the moulded plinth. However, in the event of an electrical problem it may be necessary for a competent electrician to gain access to the inside of the mouldings as follows:

Ensure that the equipment is disconnected from the electrical supply (not just switched off).

Drain any liquids contained in the process vessels and reactors, and remove any flexible tubing connected to the pumps, valves etc.

Drain the moulded channel in the plinth via the channel drain valve located in the recess at the left hand end, then unscrew the drain valve and remove it.

Unscrew the six fixings around the periphery of the plinth top.

Carefully raise the front of the top moulded section – the two sections are hinged at the rear. Unclip the prop that is located inside the front of the bottom moulded section then support the top section centrally at the front using the prop. Ensure that the prop is properly located in the appropriate recesses.

The electrical circuits inside the bottom moulded plinth section are accessible for working on.

A circuit diagram showing the mains and DC electrical circuits inside the plinth is included in the Electrical Wiring Diagram to assist in fault finding.

Re-assembly of the top and bottom moulded plinth sections is the inverse of the above instructions.

Freeing a seized hot water pump

In normal use the hot water pump should not require any routine maintenance and running should keep the gears free from scale due to hard water etc. However, if the water is contaminated with flakes of hardness or dirt particles then the gears inside the pump might seize because of the small operating clearances that are necessary. If the hot water pump does not operate when switched on it then it will be necessary to check the pump as follows:

Disconnect the electrical supply to the equipment.

Disconnect any flexible tubes connected to the gear pump to minimize loss of water when the pump is opened.

Remove the rectangular end cover from the head of the pump by unscrewing the four cap headed screws using a hexagon wrench (Allen key). Any water draining from the pump will drain into the top of the plinth.

Inspect the gears, cover etc for any contamination and clean as necessary but do not use any harsh abrasives or volatile solvents on the plastic gears or the anodized aluminium body.

If it is necessary to remove the plastic gears take care not to damage the gears or to lose the drive key inside the driven gear. If the gears are stubborn to remove then a pair of tweezers or similar tool may be used to extract the gears by grasping one of the flutes.

When the pump is clean replace the gears ensuring that the drive key is correctly located inside the slot in the driven shaft. Ensure that the gears are free to rotate before replacing the end cover.

Ensure that the sealing gasket is correctly located in the groove on the end face of the pump body then replace the end cover and secure it using the four screws.

Reconnect the flexible connections and reconnect the electrical supply. Ensure that the hot water vessel is full with water then check satisfactory operation of the pump.

Laboratory Teaching Exercises

Index to Exercises

Exercise A: On/off level switch

Objective

To control the level in the process vessel using an on/off level switch with a Normally Closed solenoid valve (SOL1) controlling inflow to the vessel.

Overview

The on/off level switch used for this exercise is a float switch, i.e. a vertical probe with a moving float which rises with the water level until it closes the circuit of the switch. This activates an on/off valve to control the flow into the process vessel.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. The apparatus must not be left unattended once in operation. Manual operation of the inlet pressure regulator and the drain valves should be used to control the fluid level if the vessel volume reaches the overflow pipe or the drainage channel in the plinth becomes full of water.

Run the PCT40 software and select Section 1: Level Control (inflow). Select the  icon to view the mimic diagram screen.

Open the valve SOL1 and allow water into the process vessel, as follows: Check that the ‘Controller’ radio button is selected in the On/Off – Solenoid 1 box on the left of the screen. Select ‘Control’ below the Tank Level sensor display, to open the PID controller window. Choose ‘Manual’ Mode of Operation, then set ‘Manual Output’ to 100% and click on ‘Apply’. There should be an audible click as the valve opens, and water should begin to flow into the process vessel. Close the PID controller window.

Open the drain valve in the base of the vessel to allow water to drain from the vessel. Check the flow rate with the reading from the flow meter. If the flow rate is not between 1350ml/min and 1450ml/min then the pressure regulator will need adjusting as follows:

Pull the large grey knob on the pressure regulator away from the body of the regulator.

Gradually turn the knob to adjust the pressure regulator setting until the flow rate is approximately 1400ml/min. Clockwise rotation opens the valve, anticlockwise rotation closes the valve.

Depending on variations in the local water pressure, the flow rate figure may oscillate.

If local water pressure is low then a lower value than 1400ml/min may be set. Where this is the case, always set a value slightly lower than the maximum flow rate to protect against spikes in pressure.

Push the knob back in to fix the setting.

NOTE: If the flow rate exceeds 1500ml/min then the flow meter may give a reading of 0ml/min. The flow meter is not designed to read flow rate values of greater than 1500ml/min. The regulator valve must be closed to reduce the flow below this value.

On the lid of the large process vessel, loosen the locking nut at the top of the level switch and adjust the height of the switch to a suitable starting value. An initial value of approximately 200mm is suggested.

Partially close the drain valve at the base of the large process vessel, limiting flow out of the vessel.

In the Sample/Configure menu of the software, check that data logging is set to automatic at intervals of five seconds. Check that the pressure reading L1 is varying with the rising water levels. In the On/Off – Solenoid 1 box, select the radio button for 'Level (Float) Switch' control.

Select the GO icon to begin data logging.

Observe that the large process vessel fills with water until the fluid level reaches the level switch. Observe the action of the level switch as the fluid level rises further. Note the position of the switch when SOL 1 is closed by the control software.

Observe the action of the level switch as the fluid level falls once more, and note the position of the switch when the control software allows SOL 1 to open again.

Continue logging until the oscillations in fluid level reach stable values for magnitude (height) and duration. Select the STOP icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3:

Following the previous section of this experiment, create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2.

Allow the fluid level oscillations to settle to steady values.

Open valve SOL 3, so that SOL2 and SOL3 are both open.

Note whether the fluid level oscillates around the pressure switch set point or continues to drain from the process vessel.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Select the icon to finish data logging.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus:

Pull the knob outwards from the body of the regulator.

Turn the knob gradually anticlockwise to reduce the indicated flow rate to 1000ml/min (or to a value that is approximately 2/3 of the previous flow rate if this was less than 1400ml/min).

Lock the value by pushing the knob back in.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Alter the feed rate to 700ml/min (or to half the original flow rate if this was less than 1400ml/min).

Allow the fluid level oscillations to stabilise again.

Select the icon to finish data logging.

Continue to reduce the feed rate and log the results until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate). Remember to create a new results sheet for each set of data.

Open the pressure regulator again: Pull the knob outwards from the body of the regulator and turn the knob steadily clockwise until the flow rate (indicated in the software) returns to 1400ml/min, or to the original flow rate if this was less. Lock the knob by pushing it back in.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate.

Create a new results sheet by selecting the appropriate icon in the tool bar of the software.

Select the  icon to begin data logging.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate. Wait until the oscillations stabilise in magnitude and duration.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve. Continue data logging until the oscillations in fluid level reach stable values.

Select the  icon to finish data logging.

Effect of Vessel Volume

In the software, close the valve SOL1 as follows: Select the ‘Controller’ radio button. Select ‘Control’ as at the start of the exercise, to open the PID controller window. Check that ‘Manual’ Mode of Operation is selected then set ‘Manual Output’ to 0% and click on ‘Apply’. There should be an audible click as the valve closes, and flow into the large process vessel should stop.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate and inlet/outlet flow rates may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise A).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations in which each type of variation in starting conditions might occur. For each example, consider the suitability of the switch used for that particular application.

Exercise B: Differential level switch

Objective

To control the level in the process vessel using a differential level switch with a Normally Closed solenoid valve (SOL1) controlling inflow to the vessel.

Overview

The differential level switch used in this exercise consists of a pair of electrodes and a fixed earth rod (a metal ruler). The switch works by measuring the conductance between the electrodes and the earth rod. The conductance through air is different to that through water, and hence the conductance measured differs if one or both electrodes are touching the water. This can be used to create a switch that is triggered by the water level within the process vessel, with the electrodes adjusted to different heights to give a maximum and minimum level.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Check that the differential level switch is connected correctly to the plinth. The lead ending in three banana plugs should be connected at the opposite end to the back of the plinth. The three banana plugs should be connected as follows:

The green plug (green and yellow wire) to the socket on the back of the differential level switch (the connection behind the metal ruler).

The blue plug (blue wire) to the top of the left-hand rod on the differential level switch, which should be positioned to give the low level setpoint.

The red plug (brown wire) to the top of the right-hand rod on the differential level switch, which should be positioned to give the high level setpoint.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

NOTE: The differential level switch must be primed before use. Priming is described as part of this experimental procedure.

Switch on mains power to the console. The apparatus should not be left unattended once in operation. Manual operation of the inlet pressure regulator and drain valve should be used to control the fluid level if the vessel volume reaches the overflow pipe, or the drainage channel in the plinth becomes full of water.

Run the PCT40 software and select Section 1: Level Control (inflow). Select the icon to view the mimic diagram screen.

Loosen the locking nuts at the top of the differential level switch electrodes and adjust the height of the rods to suitable starting values. It will be easier to refer the values to the ruler mounted between the rods than to the scale on the side of the vessel. Initial values of 20mm for the blue-topped rod and 50mm for the red-topped rod are suggested (the red rod should be positioned higher than the blue rod).

Partially close the drain valve at the base of the large process vessel, limiting flow out of the vessel.

In the software, check that data logging is set to automatic at intervals of five seconds.

Prime the differential level switch

The logic for the differential level switch requires the sensor to be prepared ready for use before it can be used to control the flow level.

Adjust the level switch (float switch) until the float is higher than the lower of the two electrodes on the differential level switch.

In the On/Off – Solenoid 1 box, select the radio button for ‘Level (Float) Switch’. Check that water begins to flow into the process vessel, and that the reading L1 is varying with the rising water levels.

Allow the water level to reach the lower electrode on the differential level switch.

Lower the level switch and allow the water level in the vessel to drop.

Once the level is at least 50mm below the lower of the two electrodes on the differential level switch, select the radio button for ‘Differential Level’ switch control in the On/Off – Solenoid 1 box. The differential level switch is now ready for use.

Select the icon to begin data logging.

Observe that the large vessel fills with water until the fluid level reaches the differential level switch. Note the height of the fluid level relative to the switch sensors when SOL 1 is closed by the control software.

Note the fluid height relative to the switch when the control software opens SOL 1 again.

Continue logging until the oscillations in fluid level reach stable values for magnitude (height) and duration. Select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3.

Create a new results sheet by selecting the appropriate icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2.

Allow the fluid level oscillations to settle.

Open valve SOL 3. Both SOL2 and SOL3 should now be open

Note whether the fluid level oscillates around the set point or whether the fluid continues to drain from the process vessel.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Select the icon to finish data logging.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus:

Pull the knob outwards from the body of the regulator.

Turn the knob gradually anticlockwise to reduce the indicated flow rate to 1000ml/min (or to a value that is approximately 2/3 of the previous flow rate if this was less than 1400ml/min).

Lock the value by pushing the knob back in.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging

Alter the feed rate to 700ml/min (or to half the original flow rate if this was less than 1400ml/min).

Allow the fluid level oscillations to stabilise again.

Select the icon to finish data logging.

Continue to reduce the feed rate and log the results until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate). Remember to create a new results sheet for each set of data.

Open the pressure regulator again: Pull the knob outwards from the body of the regulator. Turn the knob steadily clockwise until the flow rate (indicated in the software) returns to 1400 ml/min (or to the original flow rate if this was less). Lock the knob by pushing it back in.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate. Wait until the oscillations stabilise in magnitude and duration.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve. Continue data logging until the oscillations in fluid level reach stable values.

Select the icon to finish data logging.

Return the drain valve to its partly closed position.

Effect of Vessel Volume

In the software, close the valve SOL1 as follows: Select the ‘Controller’ radio button. Select ‘Control’ as at the start of the exercise, to open the PID controller window. Check that ‘Manual’ Mode of Operation is selected then set ‘Manual Output’ to 0% and click on ‘Apply’. There should be an audible click as the valve closes, and flow into the large process vessel should stop.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate and inlet/outlet flow rates may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise B).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations in which each type of variation in starting conditions might occur. For each example, consider the suitability of the switch used for that particular application.

Exercise C: Manual operation of Normally Closed solenoid valve

Objective

To manually control the level of water in the process vessel using a pressure sensor to monitor the level with a Normally Closed solenoid valve (SOL1) controlling inflow to the vessel.

Overview

Fluid level in a process vessel can be maintained manually, without the use of automated sensor-controlled switches. In this exercise the operator uses a simple on/off switch to control flow into the process vessel in order to maintain the fluid level at the required set point.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. The apparatus should not be left unattended once in operation, and manual operation of the inlet pressure regulator and drain valve should be used to control the fluid level if the vessel volume reaches the overflow pipe, or the drainage channel in the plinth becomes full of water.

Run the PCT40 software and select Section 1: Level Control (inflow). Select the  icon to view the mimic diagram screen.

Partially close the drain valve on the bottom of the large process vessel to slightly reduce the outlet flow rate.

In the Sample menu, select ‘Configure’, and check that the software is set to Automatic sampling with a sample interval of five seconds and Continuous duration.

Observe in the software that the valve is OFF and therefore CLOSED, with no water flowing.

OPEN the valve SOL1 as follows: Check that the ‘Controller’ radio button is selected in the On/Off – Solenoid 1 box on the left of the screen. Select ‘Control’ below the Tank Level sensor display, to open the PID controller window. Choose ‘Manual’ Mode of Operation then set ‘Manual Output’ to 100% and click on ‘Apply’. There should be an audible click as the valve opens, and water should begin to flow into the process vessel.

Observe that water flows into the large process vessel.

Allow the fluid level to rise until it reaches the desired level in the vessel. 200mm is suggested.

Close the valve SOL1: In the PID control window set ‘Manual Output’ to 100%. There should be an audible click as the valve closes, and water should stop flowing into the process vessel.

Observe that the fluid level in the large process vessel falls as water continues to drain.

Select the icon to begin data logging.

By operating the valve SOL1 via the PID controller window using manual control, maintain the fluid level in the process vessel. Note the action required to maintain this level.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2.

Continue to control the height by manually operating SOL1, noting any change in the control actions required.

Open valve SOL 3. Both SOL2 and SOL3 should now be open

Continue to control the fluid level in the process vessel. Note whether it is possible to maintain the fluid level with both outlet valves open.

Close both valves SOL 2 and SOL 3 and return the fluid level to the set point.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Feed Rate

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a anticlockwise to reduce the flow to approximately 2/3 the original flow rate (1000ml/min if the suggested flow rate of 1400ml/min was used) then lock the value by pushing the knob back in.

Alter the feed rate again to approximately half the original value (700ml/min if a flow rate of 1400ml/min was used), using the pressure regulator as before.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate.

Select the icon to begin data logging.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate. Note the control actions required in the operation of valve SOL1 to maintain fluid level.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Continue to maintain the level in the process vessel.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Reset the inlet flow rate to its original value (usually 1400 ml/min), and adjust the drain valve to its original partly closed setting.

Effect of Vessel Volume

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Select the icon to begin data logging.

Manually maintain the fluid level in the tank at its Set Point level.

Select the icon to finish data logging.

If there is sufficient laboratory time then the investigations of feed rate and inlet/outlet flow rates may be repeated at this increased volume. Remember to create a new results sheet for each investigation.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise C).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the results for basic manual control during the first part of the exercise.

Exercise D: Proportional pressure input with on/off controller using Normally Closed solenoid valve

Objective

To control the level in the process vessel using an on/off controller connected to a pressure sensor, with a Normally Closed solenoid valve (SOL1) controlling inflow to the vessel.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Overview

The level control method in this exercise uses a pressure sensor with an output proportional to the pressure exerted on the sensor, calibrated in millimetres of water. This sensor is normally used to indicate the level of fluid within the large process vessel, but for this exercise the output is also used to control a flow control valve via the computer, in this instance an on/off solenoid valve.

Equipment set up

Ensure that the apparatus has been set up according to the assembly sheet (see also Appendix A in this manual). Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. The apparatus should not be left unattended once in operation, and manual operation of the inlet pressure regulator and drain valve should be used to control the fluid level if the vessel volume reaches the overflow pipe, or the drainage channel in the plinth becomes full of water.

Run the PCT40 software and select Section 1: Level Control (inflow). Select the  icon to view the mimic diagram screen.

Setting the On/Off Controller

In the PCT40 software select ‘Control’ below the Tank Level sensor display, to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. Click on 'Apply'. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale.

Type in the Set Point value at which the on/off controller will operate. A recommended starting value is 200mm for level.

Apply the settings and close the controller window.

From the Sample menu at the top of the screen, select 'Configure…' and set data logging to automatic at intervals of five seconds. Check that the reading L1 is varying with the rising water levels.

Partially close the drain valve at the base of the large process vessel, limiting flow out of the vessel.

Select the  icon to begin data logging.

Note the behaviour of SOL1 as the fluid level approaches the pressure set point.

Continue logging until the oscillations in fluid level reach stable values for magnitude (height) and duration. Select the  icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3.

Create a new results sheet by selecting the appropriate icon in the tool bar of the software.

Select the  icon to begin data logging.

In the software, select the switch to open valve SOL 2.

Allow the fluid level oscillations to settle.

Open valve SOL 3. Both SOL2 and SOL3 should now be open

Note whether the fluid level oscillates around the set point or whether the fluid continues to drain from the process vessel.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Select the  icon to finish data logging.

Set Point Value

Investigate the effect of changing the level at which the switch operates.

In the PID controller window, alter the Set Point to 100mm.

Select the  icon to begin data logging.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in fluid level until the oscillations reach stable values. Suggested values for the pressure switch set point value are 150, 250 and 300mm. Remember to create a new results sheet for each set of data.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator. Turn the knob anticlockwise until the flow rate reading is approximately 2/3 of the original value (1000ml/min is suitable if an initial value of 1400ml/min was used). Lock the setting by pushing the knob back in.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Alter the feed rate again by repeating the adjustment to the pressure regulator. Allow the fluid level oscillations to stabilise again.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate.

Select the icon to begin data logging. Continue logging until the oscillations about the set point value reach stable values, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Log the fluid level as before, and stop logging when the oscillations once more reach stable values of magnitude and duration.

Effect of Vessel Volume

In the software, open the PID controller window. Set the Mode of Operation to 'Manual' then set 'Manual Output' to 0% and click on 'Apply'. This will close the valve SOL1 and stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate, inlet/outlet flow rates and cycle time may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. 'Flowrate', 'Volume', etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise D).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations in which each type of variation in starting conditions might occur. For each example, consider the suitability of the switch and type of controller used for that particular application.

Exercise E: Proportional pressure input with time proportional control using Normally Closed solenoid valve

Objective

To control the level in the process vessel using a time-proportional controller connected to a pressure sensor, with a Normally Closed solenoid valve (SOL1) controlling inflow to the vessel.

Overview

The control system in this exercise consists of a pressure sensor with an output proportional to the pressure exerted on the sensor. The output is sent to a time proportional controller which operates an on/off flow switch. The time proportioning controller turns the output on and off at intervals. This ratio of time “on” to time “off” may be set manually, or may be set automatically by the controller which then varies the ratio according to the difference between the current control variable and the required Set Point value.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the assembly sheet (see also Appendix A in this manual). Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. The apparatus should not be left unattended once in operation, and manual operation of the inlet pressure regulator and drain valve should be used to control the fluid level if the vessel volume reaches the overflow pipe, or the drainage channel in the plinth becomes full of water.

Run the PCT40 software and select Section 1: Level Control (inflow). Select the  icon to view the mimic diagram screen. Check that ‘On/Off – Solenoid 1’ is set to ‘Controller’.

Select 'Configure' from the Sample menu, and set sampling to Automatic at intervals of 5 seconds, with duration as Continuous.

Fixed (manually set) ratio

In the PCT40 software select 'Control' below the Tank Level sensor display, to open the PID controller window.

Set P, I and D to 0.

In Manual Operation set 'Manual Output' to the percentage time during which the control valve will be open. 50% is suggested as a starting value

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 50% and a cycle time of 10s, the valve will be switched on for 5s and switched off for 5s).

Set the Mode of Operation to 'Manual Control' and click on 'Apply'. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Close the drain valve at the base of the large process vessel, preventing flow out of the vessel. The vessel will begin to fill with water. When the fluid level reaches 200mm, partially open the valve to allow water to drain slowly from the vessel.

Check that there is a new data sheet for data logging.

Select the icon to begin data logging, and observe the fluid level in the process vessel. When the level has changed by more than 50mm, select the icon to finish data logging.

Adjust the control percentage according to the change in fluid level. If the fluid level fell, decrease the percentage. If the level rose, increase it. If the change was rapid, make a change of 15 to 20%. If it was gradual, change the value by 5 or 10%.

Continue to monitor the fluid level and adjust the percentage value until the fluid maintains a constant level.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging, and log the fluid level for a few minutes. Select the icon to finish data logging.

Make a note of the settings used.

On the software screen, select the control switches for valves SOL2 and SOL3, opening the valves and allowing water to drain from the vessel until the water level is approximately 150mm.

Close SOL2 and SOL3 again.

Create a new results sheet by selecting the icon in the tool bar of the software.

Controller-controlled time proportioning

In the PCT40 software, open the PID controller window.

Set the Set Point to 200mm.

Set P to 100%.

Leave I and D set to 0.

The Manual Control setting may be ignored.

Leave the Cycle Time at 10s.

Select the Automatic Control radio button and click on 'Apply'. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the icon to begin data logging, and observe the fluid level in the process vessel. Note the behaviour of SOL1 as the fluid level approaches the Set Point.

When the oscillations around the Set Point have settled, select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2.

In the Manual Control section of the PID control window, modify the percentage value until the fluid level is maintained at a constant value

Open valve SOL 3. Both valves SOL2 and SOL3 should now be open. Modify the percentage value to maintain the fluid level in the process vessel, and note any problems with maintaining this level.

Close both valves SOL2 and SOL3 and set the percentage value back to the setting it was at the start of this section of the exercise. Note whether this value still maintains the fluid level as before.

Select the icon to finish data logging.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a half-turn anticlockwise then lock the value by pushing the knob back in.

In the Manual Control section of the PID controller window, adjust the percentage setting until a constant fluid level is maintained.

Alter the feed rate again by repeating the adjustment to the pressure regulator. Allow the fluid level oscillations to stabilise again.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Cycle Time

Create a new results sheet by selecting the icon in the tool bar of the software.

In the software, set the cycle time to 5s.

Select the icon to begin data logging.

Log the fluid level in the vessel for at least 2 minutes, and then select the icon to finish data logging.

Alter the cycle time again, to 20s.

Select the icon to begin data logging.

Log the fluid level in the vessel for at least 2 minutes, and then select the icon to finish data logging.

Reset the cycle time to 10s.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate.

Select the icon to begin data logging. Adjust the percentage of ‘On’ time to ‘Off’ time in the PID controls until a steady fluid level is achieved, continue to log for a minute more, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Log the fluid level as before, adjusting the percentage until a stable level is maintained. Log for a further minute at constant fluid level, then select the STOP icon to finish data logging.

Effect of Vessel Volume

Open the PID controller window. Set the Mode of Operation to ‘Manual’ and set ‘Manual Output’ to 0%. This will close the valve SOL 1 and stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate and inlet/outlet flow rates may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise E).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Compare the results obtained using time proportioning against those using a simple on/off controller (as in Exercises A and C).

Give examples of industrial control situations in which each type of variation in experimental conditions might occur. For each example, consider the suitability of the switch used for that particular application.

Exercise F: Manual operation of Proportioning Solenoid Valve

Objective

To manually control the level of water in the process vessel using a pressure sensor to monitor the level with a Proportioning Solenoid Valve (PSV) controlling inflow to the vessel.

Overview

For simple processes with limited input parameters that occur over a short time period, manual control may be the simplest and easiest method of process control. This exercise investigates manual control of a single input, input flow rate, to control a single parameter, fluid level.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. Valve PSV is Normally Closed, so flow into the large process vessel will not occur until the valve is in operation.

Run the PCT40 software and select Section 2: Level Control (inflow).

Partially close the drain valve on the bottom of the large process vessel to slightly reduce the outlet flow rate.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 10 seconds, with duration as Continuous.

In the software, click in the control box for the Proportioning Solenoid Valve (PSV) and enter a value of 100%. This will fully open the valve. Observe that water flows into the large process vessel.

Allow the fluid level to rise until it reaches the desired level in the vessel. 200mm is suggested.

In the software, enter a value of 0% for the PSV setting to close the valve and stop the inlet flow.

Observe that the fluid level in the large process vessel falls as water continues to drain.

Select the icon to begin data logging.

Enter a value of 50% for the PSV, then use the arrow keys to adjust this value up or down to return the fluid level in the vessel to 200mm. By continuing to operate the PSV via the software, adjust the inlet flow rate to maintain the fluid level in the process vessel at a constant value. Do not adjust the drain valve as this will change the PSV setting required.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valves SOL 2 and SOL 3.

Create a new results sheet by selecting the appropriate icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2. Adjust the PSV valve setting to maintain the fluid level in the process vessel. Note the adjustment required.

Close valve SOL 2 and open valve SOL 3. Once again note the control action required to maintain the fluid level in the process vessel.

Open valve SOL 2 so that both valves SOL 2 and SOL 3 are open. Note whether it is possible to maintain the fluid level in the vessel by controlling the PSV valve alone.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Feed Rate

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a half-turn anticlockwise then lock the value by pushing the knob back in.

Note the action required to maintain the fluid level in the process vessel.

Alter the feed rate again by repeating the adjustment to the pressure regulator. Note the action required to maintain fluid level.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Select the icon to begin data logging.

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate. Note the control actions required in the operation of the PSV valve in order to maintain fluid level.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Effect of Vessel Volume

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Select the icon to begin data logging.

Control the fluid level in the vessel for five minutes.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

If there is sufficient laboratory time then the investigations of feed rate and inlet/outlet flow rates may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise F).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the results for basic manual control during the first part of the exercise.

Retain the results for comparison with automated control as in the following exercise.

Exercise G: Proportional pressure input with PID controller using Proportioning Solenoid Valve

Objective

To control the level in the process vessel with a PID controller, using a pressure sensor to monitor the level with a Proportioning Solenoid Valve (PSV) controlling inflow to the vessel.

Overview

The proportional pressure sensor sends a signal to the controller that varies with the pressure on the sensor resulting from the depth of fluid. The controller sends a signal to the Proportioning Solenoid Valve (PSV) that is proportional to the signal from the sensor. The PSV then opens proportionally with the signal from the controller.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console. Valve PSV is Normally Closed, so flow into the large process vessel will not occur until the valve is in operation.

Run the PCT40 software and select Section 2: Level Control (inflow).

Partially close the drain valve on the bottom of the large process vessel to slightly reduce the outlet flow rate.

In the Sample menu, select ‘Configure...’ and check that the software is set to Automatic sampling with a sample interval of 10 seconds and Continuous duration.

Click on the Control button.

In the software, set the value of the fluid Set Point value to the desired height. A value of 200mm is suggested. Observe that the PSV now operates and water begins to flow into the large process vessel.

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are Proportional Band (P) of 10%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

Select the icon to begin data logging as the process vessel continues to fill with water.

Observe the fluid level in the vessel and the action of the PSV as the level approaches the Set Point value. The fluid level will oscillate about the Set Point value. Continue logging until the oscillations reach stable values, then select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by operating the Normally Closed solenoid valves SOL 2 and SOL 3:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2. Observe the variation in the PSV setting displayed in the software, and the oscillations in fluid level in the process vessel.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Close valve SOL 2 and open valve SOL 3.

Select the icon to begin data logging.

Once again note the operation of the PSV and observe the fluid level in the process vessel.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Open valve SOL 2 so that both valves SOL 2 and SOL 3 are open. Note whether it is possible to maintain the fluid level in the vessel by controlling the PSV valve alone. If the fluid level remains stable, wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging. If the fluid level falls continuously, wait until the vessel is half empty then stop logging.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Pressure Switch Set Point

Investigate the effect of changing the Set Point for the pressure sensor.

Create a new results sheet by selecting the icon.

In the software, alter the pressure switch set point to 100mm.

Select the icon to begin data logging.

Continue logging until the oscillations reach constant magnitude and duration, then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in fluid level until the oscillations reach stable values. Suggested values for the pressure switch set point value are 150, 250 and 300mm. Remember to create a new results sheet for each set of data.

PID Settings and optimisation

With proportional control action, the controller produces a signal that is proportional to the error (the difference between the monitored variable and the set point value). This creates an offset between setpoint value and actual value (the controller only supplies an output when there is an error, so there is no controller output when the value is not at the set point). It also generates an overshoot (the system will oscillate above and below the setpoint value at the start of the control period until stability is attained).

Without logging the data:

Alter the setting for Proportional Band (P) in the software to 100%, and continue to observe the variations in fluid level.

Alter the P setting to 1%. Observe the changes in fluid level.

Experiment with other values, making notes of the effect on fluid level oscillation and level control.

Return the P setting to 10%.

With integral control action, the controller gives an output that is proportional to the time integral of the error. Integral control action can potentially be used alone to control a process, but is normally used in conjunction with proportional action. It can be used with proportional action to eliminate offset. It can also cause higher maximum deviation and a longer response time than with proportional action alone.

Without logging the data:

Alter the setting for Integral Time Constant (I) to 5, and observe the variations in fluid level.

Alter the I setting to 50. Observe the changes in fluid level.

Experiment with other values, making notes of the effect on fluid level oscillation and level control.

With derivative control action, the controller gives an output that is proportional to the derivative of the rate of change of the error. The output is related only to the rate of change, not to the magnitude of the error. Derivative control action cannot be used alone, but must be combined with another action such as proportional control action. When used with proportional action, derivative control can eliminate excessive oscillation. It cannot eliminate offset errors inherent in proportional action

Without logging the data:

Change the I setting back to 0 (zero).

Alter the setting for D to 1, and observe the variations in fluid level.

Alter the D setting to 5. Observe the changes in fluid level.

Leaving P and I constant, experiment with different settings of D while making notes of the effect on fluid level oscillation and level control.

Return the D setting to 0.

Pick two illustrative values for each of the P, I and D settings.

For each of these values, create a new results sheet and start data logging. Set the new value and log the result until the oscillations stabilise, or for five minutes if this is longer. Return each parameter to its original value after investigating the two different settings, and change only one value for each data collection run.

Proportional, integral and derivative control actions may be combined to eliminate offset, reduce maximum deviation and minimise the frequency of oscillation. Finding the optimum values of P, I and D for a particular process is often referred to as *tuning* or *optimisation*.

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Create a new results sheet by selecting the  icon in the tool bar of the software.

Set the set point level to 0mm and allow the process vessel to empty.

Set the software to provide On/Off control (set P to 0).

Set the set point to 150mm (this allows room for considerable overshoot during the initial tuning process).

Select the 

icon to begin data logging.

Wait as the fluid level rises to the set point and overshoots. Continue logging as the controller operates the PSV and the fluid level falls again to below the set point value.

Wait until the fluid level begins to rise once more, then select the 

icon to finish data logging.

Plot a graph of time against fluid level.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

$I = t$

$D = t / 6$

Set these values in the software, and return the set point level to 0mm to drain the vessel.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Set the set point to 200mm.

Select the  icon to begin data logging.

Observe the fluid level as it approaches the set point level. Wait until any oscillations have stabilised, then select the  icon to finish data logging.

From these new results, plot a graph of fluid level against time and observe the shape of the graph.

Proportional control sets the gain of the controller. If a slow response is observed, or large oscillations occur in fluid level, reduce the value of P. Investigate the results of the changed value by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Return the value of P to the basic value obtained from the initial measurements.

Integral control can be adjusted to reduce offset in the controlled fluid level. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are rapid or large, reduce the value of D. Investigate the results of the changed value by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Leaving the optimised value of D, set the values of P and I to the optimised values found by experiment. Perform a final test run, logging the fluid level over time as it rises from 0mm. Compare this to the initial graph.

Feed Rate

Create a new results sheet by selecting the  icon in the tool bar of the software.

Select the  icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a half-turn anticlockwise then lock the value by pushing the knob back in.

Note the action of the PSV.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the  icon to finish data logging.

Repeat the feed rate exercise by reducing the inlet flow rate in steps until the fluid level in the vessel no longer returns to the Set Point level (the drain rate exceeds the inlet flow rate). For each step create a new results sheet before starting data logging, and continue logging until the oscillations stabilise.

Effect of Vessel Volume

In the software, close the valve SOL1. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of disturbances, Set Point value, PID settings and feed rate may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise G).

Each set of data not already graphed as part of the procedure should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. Compare the results obtained using PID control against those using a simple on/off controller (as in Exercises A and C) and time proportioning control (Exercise F).

Give examples of industrial control situations in which each type of variation in experimental conditions might occur. For each example, consider the suitability of PID control for that particular application.

Exercise H: Manual operation of Normally Closed solenoid valve

Objective

To manually maintain the level in a process vessel using a Normally Closed solenoid valve to control outflow rate from the vessel.

Overview

Outflow from the large process vessel is directed through a Normally Closed solenoid valve. By manually switching this valve on or off via the computer, the valve is opened or closed and outflow from the vessel can be controlled in order to balance the inflow to the vessel and maintain the fluid level at a set point value.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console and run the PCT40 software. Select ‘Section 3: Level Control (outflow)’.

In the PCT40 software, set the PSV to operate at 75%. Refer to the flow meter display and adjust the PSV setting to give a flow rate of 1 L/min using the arrow keys.

Check that the level reading L1 is varying with the rising water levels.

Partially close the drain valve at the base of the large process vessel to produce a constant low outflow to drain.

From the Sample menu, select ‘Configure...’ and set the software to Automatic sampling with a sample interval of ten seconds and a Continuous duration.

Select the 

icon to begin data logging.

Allow the fluid level in the process vessel to approach a value of 200mm. By switching the valve SOL 2, control the outflow rate in order to maintain the fluid level at 200mm.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valve SOL 3:

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 3. Operate valve SOL 2 in order to maintain a fluid level of 200mm.

Close valve SOL 3 and continue to maintain the fluid level.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Feed Rate

Select the icon to begin data logging.

To change the inlet feed rate, change the setting of the Proportioning Solenoid Valve as shown in the software. A step change may be produced by typing the new setting directly into the display box. A change of 20% of total range up or down is suggested.

Use the valve SOL 2 to maintain fluid level. Note the change in control action required due to the inlet flow rate change, and whether the change in flow rate was an increase or a decrease.

Change the PSV valve setting to 100% (fully open). Note whether the fluid level can be maintained using SOL 2 alone at this maximum inlet flow rate.

Change the PSV valve setting to 0% (fully closed). Again note whether the fluid level can be maintained using only valve SOL 2 at this minimum inlet flow rate.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Return the PSV valve setting to the valve it was set to before commencing the next section of the exercise.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Select the icon to begin data logging.

Decrease the outflow rate by completely closing the drain valve in the base of the vessel. This will decrease the outflow rate compared to the inflow rate.

Continue to control of the valve SOL 2 to maintain fluid height in the process vessel.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Select the STOP icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Return the drain valve to a partially closed position.

Effect of Vessel Volume

In the software, set the PSV to 0%. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel, and fit the removable inner cylinder, pressing it down firmly to seal the bottom edge. This reduces the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Select the GO icon to begin data logging.

Maintain the fluid level at the Set Point by controlling valve SOL 2.

Select the STOP icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

If there is sufficient laboratory time then the investigations of disturbances, feed rate and inlet/outlet flow rates may be repeated at this reduced volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Feed Rate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise H).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the results for basic manual control during the first part of the exercise.

Retain the results for comparison with automated control as in the following exercise.

Exercise I: Proportional pressure input with on/off controller using Normally Closed solenoid valve

Objective

To control the level in a process vessel using an on/off controller connected to a pressure sensor, with a Normally Closed solenoid valve (SOL2) controlling outflow from the vessel.

Overview

The proportional pressure control method in this exercise consists of a pressure sensor with an output proportional to the pressure exerted on the sensor. The output is sent to an on/off controller that controls a Normally Closed solenoid valve.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console and run the PCT40 software. Select ‘Section 3: Level Control (outflow)’.

In the PCT40 software, set the PSV to operate at 75%. Refer to the flow meter display and adjust the PSV setting to give a flow rate of 1 L/min using the arrow keys.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 10 seconds, with duration as Continuous.

Setting the On/Off Controller

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale.

Type in the Set Point value at which the on/off controller will operate. A recommended starting value is 200mm for pressure.

Apply the settings and close the controller window.

Set data logging to automatic at intervals of ten seconds. Check that the level reading L1 is varying with the rising water levels.

Partially close the drain valve at the base of the large process vessel to produce a constant low outflow to drain.

Select the icon to begin data logging.

Note the behaviour of the valve SOL 2 as the fluid level approaches the pressure set point.

Continue logging until the oscillations in fluid level reach stable values for magnitude (height) and duration. Select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valve SOL 3:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

On the software screen, select the switch that operates valve SOL 3.

Allow the fluid level oscillations to settle to their original values.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Close the valve SOL 3.

Allow the fluid level oscillations to settle to their original values.

Select the icon to finish data logging.

Set Point

Investigate the effect of changing the pressure level at which the on/off controller operates SOL 1:

In the software, select the Controller button then alter the Set Point to 100mm. Apply the new setting and close the controller window.

Select the icon to begin data logging.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in fluid level until the oscillations reach stable values. Suggested pressure values for the set point value are 150, 200 and 300mm. Remember to create a new results sheet for each set of data.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a half-turn anticlockwise then lock the value by pushing the knob back in.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Alter the feed rate again by repeating the adjustment to the pressure regulator. Allow the fluid level oscillations to stabilise again.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Decrease the outflow rate by completely closing the drain valve in the base of the vessel. This will decrease the outflow rate compared to the inflow rate.

Select the icon to begin data logging. Continue logging until the oscillations about the set point value reach stable values, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Log the fluid level as before, and stop logging when the oscillations once more reach stable values of magnitude and duration.

Return the drain valve to a partially closed position.

Effect of Vessel Volume

In the software, close the valve SOL1. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove the inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate, inlet/outlet flow rates and cycle time may be repeated at this increased volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise I).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations in which each type of variation in starting conditions might occur. For each example, consider the suitability of the switch and type of controller used for that particular application.

Exercise J: Proportional pressure input with time proportional controller using Normally Closed solenoid valve

Objective

To control the level in the process vessel using a time-proportional controller connected to a pressure sensor, with a Normally Closed solenoid valve (SOL2) controlling outflow from the vessel.

Overview

The control system in this exercise consists of a pressure sensor with an output proportional to the pressure exerted on the sensor. The output is sent to a time proportional controller which operates an on/off flow switch. The time proportioning controller turns the output on and off at intervals. This ratio of time “on” to time “off” may be set manually, or may be set automatically by the controller which then varies the ratio according to the difference between the current control variable and the required Set Point value.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside large process vessel. Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve SOL1 at the front right of the plinth.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console.

Run the PCT40 software. Select ‘Section 3: Level Control (outflow)’.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 10 seconds, with duration as Continuous.

Fixed (manually set) ratio

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set P, I and D to 0.

In Manual Control set the percentage time during which the control valve will be open. 50% is suggested as a starting value

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 50% and a cycle time of 10s, the valve will be switched on for 5s and switched off for 5s).

Select the Manual Control radio button and click on ‘Apply’. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Close the drain valve at the base of the large process vessel, preventing flow out of the vessel. The vessel will begin to fill with water. When the fluid level reaches 200mm, partially open the valve to allow water to drain slowly from the vessel.

Check that there is a new data sheet for data logging.

Select the icon to begin data logging, and observe the fluid level in the process vessel. When the level has changed by more than 50mm, select the icon to finish data logging.

Adjust the control percentage according to the change in fluid level. If the fluid level fell, decrease the percentage. If the level rose, increase it. If the change was rapid, make a change of 15 to 20%. If it was gradual, change the value by 5 or 10%.

Continue to monitor the fluid level and adjust the percentage value until the fluid maintains a constant level.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging, and log the fluid level for a few minutes. Select the icon to finish data logging.

Make a note of the settings used.

On the software screen, select the control switches for valve SOL3, opening the valve and allowing water to drain from the vessel until the water level is approximately 150mm.

Close SOL3 again.

Create a new results sheet by selecting the icon in the tool bar of the software.

Controller-controlled time proportioning

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Set Point to 200mm.

Set P to 100%.

Leave I and D set to 0.

The Manual Control setting may be ignored.

Leave the Cycle Time at 10s.

Select the Automatic Control radio button and click on 'Apply'. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the icon to begin data logging, and observe the fluid level in the process vessel. Note the behaviour of SOL 2 as the fluid level approaches the Set Point.

When the oscillations around the Set Point have settled, select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valve SOL 3:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 3.

Leave the valve open until the fluctuations in fluid level have settled to a constant oscillation.

Close valve SOL 3. Allow the fluid level oscillations to settle to their original values.

Select the icon to finish data logging.

Set Point

Investigate the effect of changing the pressure at which the on/off controller operates:

Create a new results sheet by selecting the icon.

In the software, alter the pressure switch set point to 100mm.

Select the icon to begin data logging.

Continue logging until the oscillations reach constant magnitude and duration, then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in fluid level until the oscillations reach stable values. Suggested values for the pressure switch set point value are 150, 200 and 300mm. Remember to create a new results sheet for each set of data.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, adjust the pressure regulator on the inlet pipe of the apparatus: Pull the knob outwards from the body of the regulator, turn the knob a half-turn anticlockwise then lock the value by pushing the knob back in.

Allow the oscillations in fluid level to reach steady values of magnitude and duration.

Alter the feed rate again by repeating the adjustment to the pressure regulator. Allow the fluid level oscillations to stabilise again.

Continue to reduce the feed rate until the fluid level in the vessel no longer returns to the set point level (the drain rate exceeds the inlet flow rate).

Select the icon to finish data logging.

Cycle Time

Create a new results sheet by selecting the icon in the tool bar of the software.

In the software, set the cycle time to 5s.

Select the icon to begin data logging.

Log the fluid level in the vessel for at least 2 minutes, and then select the icon to finish data logging.

Alter the cycle time again, to 20s.

Select the icon to begin data logging.

Log the fluid level in the vessel for at least 2 minutes, and then select the icon to finish data logging.

Reset the cycle time to 10s.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Decrease the outflow rate by closing the drain valve in the base of the vessel, but do not completely close the valve. This will decrease the outflow rate compared to the inflow rate.

Select the icon to begin data logging. Continue logging until the oscillations about the set point value reach stable values, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Log the fluid level as before, and stop logging when the oscillations once more reach stable values of magnitude and duration.

Effect of Vessel Volume

In the software, close the valve SOL1. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel, and fit the removable inner cylinder, pressing it down firmly to seal the bottom edge. This reduces the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of Set Point value, feed rate and inlet/outlet flow rates may be repeated at this reduced volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise J).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Compare the results obtained using time proportioning against those using a simple on/off controller (as in Exercises H and I).

Discuss the effect of varying the Cycle Time on both the accuracy of control and wear of the valve being controlled.

Give examples of industrial control situations in which each type of variation in experimental conditions might occur. For each example, consider the suitability of time proportional control for that particular application.

Exercise K: Manual control of peristaltic outlet pump speed

Objective

To manually maintain the level in a process vessel by varying the speed of a peristaltic pump in order to control outflow rate from the vessel.

Overview

Outflow from the large process vessel is directed through a peristaltic pump. By manually controlling the pump speed via the computer, the outflow from the vessel can be controlled in order to balance the inflow to the vessel and maintain the fluid level at a set point value.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside the large process vessel.

Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve PSV1 at the front right of the plinth. Take a length of 4.8mm diameter peristaltic tubing with one self-sealing end and one open end, and connect the self-sealing fitting to the drain tube inserted through the lid of the large process vessel. Pass the peristaltic tube from right to left through the peristaltic pump A, but do not yet close the pump. Direct the open end to a suitable drain.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

Switch on mains power to the console and run the PCT40 software. Select ‘Section 4: Level Control (outflow)’.

In the PCT40 software, set the PSV to operate at 75%. Refer to the flow meter display and adjust the PSV setting to give a flow rate of 1000 ml/min using the arrow keys.

Check that the level reading L1 is varying with the rising water levels to give an electronic reading of fluid level in the process vessel.

Partially close the drain valve at the base of the large process vessel to produce a constant low outflow to drain.

Select 'Configure' from the Sample menu, and set sampling to Automatic at intervals of 10 seconds, with duration as Continuous.

In the software, set a value of 20% for peristaltic pump speed. The pump should start working. If the pump does not start immediately, increase the speed value to 50%. Once the pump is working, carefully close the top of the pump, ensuring that the silicone tubing passes through the entry and exit holes and is not trapped by the lid. Fluid should now be drawn down out of the process vessel through the pump to drain.

Select the  icon to begin data logging.

Allow the fluid level in the process vessel to approach a value of 200mm. By altering the speed of the pump A in the software, control the outflow rate in order to maintain the fluid level at 200mm.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by opening the Normally Closed solenoid valve SOL 3:

Select the  icon to begin data logging.

In the software, select the switch to open valve SOL 3. Change the speed of pump A by using the arrow keys, and alter the outflow rate in order to maintain a fluid level of 200mm. Note the change in control action required to maintain fluid level with valve SOL 3 open.

Close valve SOL 3 and continue to maintain the fluid level.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Feed Rate

Select the  icon to begin data logging.

To change the inlet feed rate, change the setting of the Proportioning Solenoid Valve as shown in the software. A step change may be produced by typing the new setting directly into the display box. A change of 20% up or down is suggested.

Use the speed of pump A to control outflow rate maintain fluid level. Note the change in control action required due to the inlet flow rate change, and whether the change in flow rate was an increase or a decrease.

Change the PSV valve setting to 100% (fully open). Note whether the fluid level can be maintained using pump A alone at this maximum inlet flow rate.

Change the PSV valve setting to 0% (fully closed). Again note whether the fluid level can be maintained using only pump A at this minimum inlet flow rate.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Return the PSV valve setting to the value it was set to before commencing the next section of the exercise.

Effect of Inlet and Outlet Flow Rates

Investigate the effect of an inflow rate greater than the outflow rate, and of an outflow rate greater than the inflow rate:

Select the  icon to begin data logging.

Decrease the outflow rate by completely closing the drain valve in the base of the vessel. This will decrease the outflow rate compared to the inflow rate.

Note the change required in control of pump A to maintain fluid height in the process vessel.

Increase the outflow rate compared to the inflow rate by fully opening the drain valve.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Return the drain valve to a partially closed position.

Effect of Vessel Volume

In the software, set the PSV to 0%. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel and remove inner cylinder. This increases the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Select the  icon to begin data logging.

Maintain the fluid level in the tank at the Set Point level by controlling pump A.

Select the icon to finish data logging.

Create a new results sheet by selecting the  icon.

If there is sufficient laboratory time then the investigations of disturbances, feed rate and inlet/outlet flow rates may be repeated at this reduced volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Feed Rate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise K).

Each set of data should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the results for basic manual control during the first part of the exercise.

Exercise L: Proportional pressure input with PID controller to control peristaltic outlet pump speed

Objective

To control the level in the process vessel with a PID controller, using a pressure sensor to monitor the level with a peristaltic pump controlling outflow to the vessel.

Overview

The proportional pressure sensor sends a signal to the controller that varies with the pressure on the sensor resulting from the depth of fluid. The controller sends a signal to the peristaltic pump that is proportional to the signal from the sensor. The pump speed increases or decreases proportionally with the signal from the controller.

Equipment Required

PCT40 bench with large process vessel, inner cylinder and supplied flexible tubing.

Equipment set up

Ensure that the apparatus has been set up according to the assembly sheet (see also Appendix A in this manual). Ensure that the inlet connector for the apparatus (on the right of the plinth behind the pressure regulator) is connected to a suitable mains water supply. Check that the central cylinder is securely in position inside the large process vessel.

Using a suitable length of tubing, connect the self-sealing connection socket on the base of the large process vessel to the quick release connection on the valve PSV1 at the front right of the plinth. Take a length of 4.8mm diameter peristaltic tubing with one self-sealing end and one open end, and connect the self-sealing fitting to the drain tube inserted through the lid of the large process vessel. Pass the peristaltic tube from right to left through the peristaltic pump A, but do not yet close the pump. Direct the open end to a suitable drain.

The drain valve at the end of the plinth should be directed to a drain and left open. Solenoid valves 2 and 3 should be connected to a suitable drain using the tubing supplied. The drain valve in the base of the large process vessel should also be connected directly to drain using flexible tubing.

Connect the apparatus to a suitable PC on which the software has been installed using the pale grey USB cable supplied. The flat connector on the cable connects to the PC, usually via a socket at the back. The other end connects to the socket on the orange panel on the front of the plinth. Check that the PC is working and switched on.

Procedure

NOTE: Peristaltic pumps typically do not begin to operate until the input signal reaches approximately 30%. When controlling a peristaltic pump with a PID controller, the pump will therefore not begin to operate if the Proportional Band is too large (as the controller will not send a large enough signal to start the pump). If the pump fails to operate after changing the Proportional Band, try decreasing the value of PB.

Switch on mains power to the console. Valve PSV is Normally Closed, so flow into the large process vessel will not occur until the valve is in operation.

Run the PCT40 software. Select ‘Section 4: Level Control (outflow)’.

In the software, open the PSV by selecting a setting of 100%. Observe that water begins to flow into the process vessel.

In the software, set the fluid Set Point level to 0mm, wait until the peristaltic pump begins to operate, then close the lid on the pump. Take care that the tubing through the pump passes through the inlet and outlet holes and is not pinched by the lid of the pump.

Partially close the drain valve on the bottom of the large process vessel to slightly reduce the outlet flow rate.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 10 seconds, with duration as Continuous.

In the software, click on the PID controller button and set the value of the fluid Set Point to the desired height. A value of 200mm is suggested.

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are Proportional Band (P) of 5%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

Select the icon to begin data logging as the process vessel continues to fill with water.

Observe the fluid level in the vessel and the action of the peristaltic pump as the level approaches the Set Point value. The fluid level will oscillate about the Set Point value. Continue logging until the oscillations reach stable values, then select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the outflow from the vessel by operating the Normally Closed solenoid valves SOL 2 and SOL 3:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

In the software, select the switch to open valve SOL 2. Observe the variation in the peristaltic speed setting displayed in the software, and the oscillations in fluid level in the process vessel.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Close valve SOL 2 and open valve SOL 3.

Select the icon to begin data logging.

Once again note the operation of the peristaltic pump and observe the fluid level in the process vessel.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Open valve SOL 2 so that both valves SOL 2 and SOL 3 are open. Note whether it is possible to maintain the fluid level in the vessel by controlling the peristaltic pump speed alone. If the fluid level remains stable, wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging. If the fluid level falls continuously, wait until the level is 50mm below the Set Point then stop logging.

Close both valves SOL 2 and SOL 3 and allow the fluid to return to the set point.

Set Point

Investigate the effect of changing the pressure Set Point for the controller:

Create a new results sheet by selecting the icon.

In the software, alter the pressure switch set point to 100mm.

Select the icon to begin data logging.

Continue logging until the oscillations reach constant magnitude and duration, then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in fluid level until the oscillations reach stable values. Suggested values for the pressure switch set point value are 150, 250 and 300mm. Remember to create a new results sheet for each set of data.

PID Settings and optimisation

With proportional control action, the controller produces a signal that is proportional to the error (the difference between the monitored variable and the set point value). This creates an offset between setpoint value and actual value (the controller only supplies an output when there is an error, so there is no controller output when the value is not at the set point). It also generates an overshoot (the system will oscillate above and below the setpoint value at the start of the control period until stability is attained).

Without logging the data:

With the I and D settings at 0s (zero), observe the variations in fluid level.

Alter the setting for Proportional Band (P) in the software to 10%, and continue to observe the variations in fluid level.

Alter the P setting to 1%. Observe the changes in fluid level.

Experiment with other values, making notes of the effect on fluid level oscillation and level control.

Return the P setting to 5%.

With integral control action, the controller gives an output that is proportional to the time integral of the error. Integral control action can potentially be used alone to control a process, but is normally used in conjunction with proportional action. It can be used with proportional action to eliminate offset. It can also cause higher maximum deviation and a longer response time than with proportional action alone.

Without logging the data:

Alter the setting for Integral Time Constant (I) to 1s, and observe the variations in fluid level.

Alter the I setting to 10s. Observe the changes in fluid level.

Experiment with other values of I, making notes of the effect on fluid level oscillation and level control.

Return the I setting to 0s.

With derivative control action, the controller gives an output that is proportional to the derivative of the rate of change of the error. The output is related only to the rate of change, not to the magnitude of the error. Derivative control action cannot be used alone, but must be combined with another action such as proportional control action. When used with proportional action, derivative control can eliminate excessive oscillation. It cannot eliminate offset errors inherent in proportional action

Without logging the data:

Alter the setting for D to 1s, and observe the variations in fluid level.

Alter the D setting to 5s. Observe the changes in fluid level.

Leaving P and I constant, experiment with different settings of D while making notes of the effect on fluid level oscillation and level control.

Return the D setting to 0s.

Pick two illustrative values for each of the P, I and D settings.

For each of these values, create a new results sheet and start data logging. Set the new value and log the result until the oscillations stabilise, or for five minutes if this is longer. Return each parameter to its original value after investigating the two different settings, and change only one value for each data collection run.

Proportional, integral and derivative control actions may be combined to eliminate offset, reduce maximum deviation and minimise the frequency of oscillation. Finding the optimum values of P, I and D for a particular process is often referred to as *tuning* or *optimisation*.

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Create a new results sheet by selecting the icon in the tool bar of the software.

Set the set point level to 0mm and allow the process vessel to empty.

Set the software to provide On/Off control (set P to 0%, I to 0s and D to 0s).

Set the set point to 150mm (this allows room for considerable overshoot during the initial tuning process).

Select the icon to begin data logging.

Wait as the fluid level rises to the set point and overshoots. Continue logging as the controller operates the peristaltic pump and the fluid level falls again to below the set point value. Wait until the fluid level begins to rise once more, then select the icon to finish data logging.

Plot a graph of time against fluid level.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

$I = t$

$D = t / 6$

Set these values in the software, and return the set point level to 0mm to drain the vessel.

Create a new results sheet by selecting the icon in the tool bar of the software.

Set the set point to 200mm.

Select the icon to begin data logging.

Observe the fluid level as it approaches the set point level. Wait until any oscillations have stabilised, then select the icon to finish data logging.

From these new results, plot a graph of fluid level against time and observe the shape of the graph.

Proportional control sets the response of the controller. If a slow response is observed, or large oscillations occur in fluid level after changing the value of P, reduce the value. Investigate the results of the changed value by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Return the value of P to the basic value obtained from the initial measurements.

Integral control can be adjusted to reduce offset in the controlled fluid level. If a significant offset is observed after changing the value of I, reduce the value. Investigate the results of any change by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are rapid or large after changing the value of D, reduce the value. Investigate the results of the changed value by plotting a graph of the fluid level as it rises from 0mm and comparing this to the initial results.

Leaving the optimised value of D, set the values of P and I to the optimised values found by experiment. Perform a final test run, logging the fluid level over time as it rises from 0mm. Compare this to the initial graph.

Feed Rate

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

To change the inlet feed rate, reduce the setting on the PSV to 80%.

Wait until the oscillations in fluid level stabilise in magnitude and duration, then select the icon to finish data logging.

Repeat the feed rate exercise by reducing the PSV setting in steps of 20% until the fluid level in the vessel no longer returns to the Set Point level (the drain rate exceeds the inlet flow rate). For each step create a new results sheet before starting data logging, and continue logging until the oscillations stabilise.

Effect of Vessel Volume

In the software, set the PSV setting to 0%. This will stop flow into the large process vessel.

Fully open the drain valve in the base of the large process vessel and allow the water to drain from the vessel.

Carefully remove the lid on top of the large process vessel, and fit the removable inner cylinder, pressing it down firmly to seal the bottom edge. This reduces the effective volume of the process vessel.

Replace the lid and partially close the drain valve.

Repeat the procedure described at the start of the exercise, remembering to create a new results sheet before commencing data logging.

If there is sufficient laboratory time then the investigations of disturbances, Set Point value, PID settings and feed rate may be repeated at this reduced volume.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise M).

Each set of data not already graphed as part of the procedure should be plotted on a graph of fluid level against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. Compare the results obtained using PID control against those using a simple on/off controller (as in Exercise K).

Give examples of industrial control situations in which each type of variation in experimental conditions might occur. For each example, consider the suitability of PID control for that particular application.

Exercise M: Manual control of Heater

Objective

To control the temperature in a process vessel manually by controlling power to a heating element.

Overview

The temperature within the process vessel is monitored using a thermocouple type sensor. By manually switching the power to a heating element on or off, the temperature within the vessel is regulated to maintain the required set point.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Switch on mains power to the console and run the PCT40 software. Select ‘Section 5: Temperature Control (direct batch heating)’.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 30 seconds, with duration as Continuous.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water and the level has reached the level sensor mounted in the lid, then set the PSV to 0%.

Disconnect the tube from the small process vessel, and then disconnect the other end from the PSV.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the push fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to a suitable drain. Open the drain valve at the end of the tube.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Check that the temperature reading T1 is a sensible value (usually between 5 and 30 degrees Celsius depending on mains water temperature).

A target temperature for the fluid in the vessel is required. 40 degrees centigrade is suggested. (If the mains water temperature is very high- approaching or exceeding 30 °C- then 50 °C may instead be used as the target Set Point temperature)

The heating element is switched on and off manually using the switch on the software screen. Switch on the heater, and observe the temperature T1. Check that this rises as the heater operates.

Heating Characteristics in Batch Operation

The temperature in the vessel may be manually controlled by switching the power to the heating element off and on. When using manual control, consideration should be given to the following:

Time lag between applying a control action and observing a response.

Differences in the rate of heating and cooling.

Take notes on these and other factors that affect the control actions required to reach and then obtain a constant temperature within the process vessel.

Select the GO icon to begin data logging.

Manually control the temperature in the tank for a period of five minutes.

Select the STOP icon to finish data logging.

Create a new results sheet by selecting the icon.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by passing cold water through the coil inside the vessel:

Select the GO icon to begin data logging.

In the software, send cold water through the coil within the process vessel by setting the PSV to 50%.

Control the heater to maintain the temperature in the vessel.

Increase the PSV setting to 100%.

Continue to control the temperature at the chosen Set Point value.

Set the PSV back to 0%, and continue to control the temperature within the vessel.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Disturbances’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise M).

Each set of data should be plotted on a graph of temperature T1 against time.

Write up your experiment, commenting on the heating and cooling characteristics of batch operation and the actions required for manual control of the process. Give reasons for any time delay between applying a control action and observing a response. Explain the difference in heating and cooling rates. Give examples of industrial control situations in which a disturbance of the kind investigated might occur.

Exercise N: Proportional temperature input with on/off control

Objective

To control the temperature in a process vessel using an on/off controller connected to a temperature sensor, by controlling power to a heating element.

Overview

The temperature within the process vessel is monitored using a thermocouple type sensor. The output is sent to an On/Off controller that switches a heating element on or off to maintain the required set point temperature within the vessel.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the USB cable supplied.

Switch on mains power to the console and run the PCT40 software. Select 'Section 5: Temperature Control (direct batch heating)'.

Select 'Configure' from the Sample menu, and set sampling to Automatic at intervals of 30 seconds, with duration as Continuous.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the small process vessel, and then disconnect the other end from the PSV.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the push fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to a suitable drain. Open the drain valve at the end of the tube.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Setting the On/Off Controller

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale.

Type in the Set Point value at which the on/off controller will operate. A recommended starting value is 30 degrees Celsius. A higher Set Point temperature will be required if the mains water inlet supply temperature is close to 30 °C: a value of at least 10 degrees higher than the inlet supply is recommended.

Apply the settings and close the controller window.

From the Sample menu at the top of the screen, select Configure… and set data logging to automatic at intervals of thirty (30) seconds. Check that the reading L1 is varying with the rising water levels.

Check that the temperature reading T1 is a sensible value (usually between 5 and 30 degrees Celsius depending on mains water temperature).

Select the  icon to begin data logging.

Note the behaviour of the heating element as the temperature approaches the temperature set point. It is possible to observe heated water rising from the heating element when the power is on. The heater also responds audibly when power is switched on or off. Additionally, the switch for the heater is displayed on the mimic diagram screen within the software, allowing observation of the heater action.

The change in temperature may be most easily observed using the graph screen in the software. If the graph does not appear automatically when the graph screen is selected, select ‘T1’ for the Y axis and ‘Time’ for the x-axis, then plot the graph. New points will be added as they are logged.

Continue logging for 30 minutes. Select the  icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by passing cold water through the coil inside the vessel:

Create a new results sheet by selecting the  icon in the tool bar of the software.

Select the  icon to begin data logging.

Log for two minutes (with the software taking readings every 10 seconds), then set the PSV to 50%.

Log for 15 minutes, then set the PSV to 100%.

Continue logging for 15 minutes, then set the PSV to 0%.

Log for a final 15 minutes, then select the icon to finish data logging.

Temperature Set Point

Investigate the effect of changing the temperature at which the on/off heater switch operates:

In the software, alter the temperature set point to 50 °C.

Select the icon to begin data logging.

Log for 15 minutes, and then select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in temperature until the oscillations reach stable values. Suggested values for the temperature set point value are 60, 70 and 80 °C. Remember to create a new results sheet for each set of data.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flowrate’, ‘Volume’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise N).

Each set of data should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations in which each type of variation in starting conditions might occur. For each example, consider the suitability of an on/off controller for that particular application.

Exercise O: Proportional temperature input with time proportional control of heater

Objective

To control the temperature in the process vessel using a time-proportional controller connected to a temperature sensor, with a heating element raising the temperature of the fluid within the vessel.

Overview

The control system in this exercise consists of a pressure sensor with an output proportional to the temperature detected by the sensor. The output is sent to a time proportional controller which controls the power supply to the heating element. The time proportioning controller turns the output on and off at intervals. This ratio of time “on” to time “off” may be set manually, or may be set automatically by the controller which then varies the ratio according to the difference between the current control variable and the required Set Point value.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, via the grey USB cable supplied.

Run the PCT40 software. Select ‘Section 5: Temperature Control (direct batch heating)’.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 30 seconds, with duration as Continuous.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the small process vessel then disconnect the other end from the PSV.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the push fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to a suitable drain. Open the drain valve at the end of the tube.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Fixed (manually set) ratio

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set P, I and D to 0.

In Manual Control set the percentage time during which the heater will be on. 50% is suggested as a starting value

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 50% and a cycle time of 10s, the heater will be switched on for 5s and switched off for 5s).

Select the Manual Control radio button and click on ‘Apply’. The heater should begin to operate intermittently as the time proportional controller sends signals to control it.

Check that there is a new data sheet for data logging.

Select the  icon to begin data logging, and observe the temperature in the process vessel, T1. When the temperature has risen by more than 20 °C, select the  icon to finish data logging.

Adjust the control percentage according to the change in temperature. If the change was rapid, reduce the time ‘On’ by 25 to 30%. If it was gradual, reduce the value by 10 or 15%.

Continue to monitor the temperature and adjust the percentage value until the temperature maintains a constant level.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Select the  icon to begin data logging, and log the temperature for a few minutes. Select the  icon to finish data logging.

Make a note of the settings used.

Open the Control window and set Mode of Operation to Off. Apply and close the window.

On the software screen, set the PSV to 100% to allow cold water to flow through the coil in the vessel, cooling the process fluid.

Observe the temperature T1. When the temperature has dropped to around 20 – 30 °C, set the PSV back to 0%.

Create a new results sheet by selecting the icon in the tool bar of the software.

Controller-controlled time proportioning

In the PCT40 software, select 'Control' to open the PID controller window.

Type in the Set Point value at which the on/off controller will operate. A recommended starting value is 40 °C for level.

Set P to 100%.

Leave I and D set to 0.

The Manual Control setting may be ignored.

Leave the Cycle Time at 10s.

Select the Automatic Control radio button and click on 'Apply'. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the icon to begin data logging, and observe the temperature T1. Note the behaviour of the heater as the temperature approaches the Set Point. When the oscillations around the Set Point have settled, select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by passing cold water through the coil inside the vessel:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Log for two minutes (with the software taking readings every 30 seconds), then set the PSV to 50%.

Continue logging for 15 minutes, then set the PSV to 100%.

Continue logging for a further 15 minutes, then set the PSV to 0%.

Log for a final 15 minutes, then select the icon to finish data logging.

Temperature Set Point

Investigate the effect of changing the temperature at which the on/off heater switch operates:

Create a new results sheet by selecting the icon.

In the software, alter the temperature set point to 50 °C.

Select the icon to begin data logging.

Log the temperature for 15 minutes, then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 75 and 90 °C, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data.

Return the temperature set point to its original value.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Disturbance’, ‘Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise O).

Each set of data should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Compare the results obtained using time proportioning against those using a simple on/off controller (as in Exercise N).

For each variation investigated in the experiment, give an example of a comparable industrial control situation. For each example, consider the suitability of time proportional control for that particular application.

Exercise P: Proportional temperature input with PID control of heater

Objective

To control the temperature in the process vessel with PID control of a heating element, using a temperature sensor to monitor the temperature.

Overview

As for time proportional control, the temperature sensor sends a signal to the controller that varies with the temperature of the sensor. The controller sends a signal to the heater that is proportional to the signal from the sensor. The heater power may only be on or off, so the controller varies the time for which power is supplied to the heater.

PID control adds two extra control parameters, Integral and Derivative, which may already have been investigated in the Level Control exercises:

With proportional control action, the controller produces a signal that is proportional to the error (the difference between the monitored variable and the set point value). This creates an offset between setpoint value and actual value (the controller only supplies an output when there is an error, so there is no controller output when the value is not at the set point). It also generates an overshoot (the system will oscillate above and below the setpoint value at the start of the control period until stability is attained).

With integral control action, the controller gives an output that is proportional to the time integral of the error. Integral control action can potentially be used alone to control a process, but is normally used in conjunction with proportional action. When used with proportional action it can eliminate offset. It can also cause higher maximum deviation and a longer response time than with proportional action alone.

With derivative control action, the controller gives an output that is proportional to the derivative of the rate of change of the error. The output is related only to the rate of change, not to the magnitude of the error. Derivative control action cannot be used alone, but must be combined with another action such as proportional control action. When used with proportional action, derivative control can eliminate excessive oscillation. It cannot eliminate offset errors inherent in proportional action

Proportional, integral and derivative control actions may be combined to eliminate offset, reduce maximum deviation and minimise the frequency of oscillation. Finding the optimum values of P, I and D for a particular process is often referred to as *tuning* or *optimisation*.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Switch on mains power to the apparatus and run the PCT software. Select ‘Section 5: Temperature Control (direct batch heating)’.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the small process vessel, then disconnect the other end from the PSV.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the push fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to a suitable drain. Open the drain valve at the end of the tube.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Select ‘Configure’ from the Sample menu, and set sampling to Automatic at intervals of 30 seconds, with duration as Continuous.

In the PCT40 software, enter a set point value for the temperature of 30 degrees centigrade. If the local water temperature is close to 30 °C then a higher value may be selected. At least 10 °C higher than the mains water temperature is recommended.

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are Proportional Band (P) of 100%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

Set the software to log at intervals of 10 seconds.

Select the 

icon to begin data logging.

Log the temperature within the vessel for 10 minutes, then select the icon to stop logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by passing cold water through the coil inside the vessel:

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Log for two minutes (with the software taking readings every 10 seconds), then set the PSV to 50%.

Continue logging for 10 minutes, then set the PSV to 100%.

Continue logging for a further 10 minutes, then set the PSV to 0%.

Log for a final 10 minutes, then select the icon to finish data logging.

Temperature Set Point

Investigate the effect of changing the set point temperature:

Create a new results sheet by selecting the icon.

In the software, alter the temperature set point to 40 °C (or 10 degrees higher than the initial set point if a value other than 30 degrees was used).

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 50 and 60 °C, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data. Note that the heater circuit includes a safety cut-out that will shut off power to the heater if the vessel temperature exceeds approximately 80 °C. It is recommended that Set Point values are be kept well below this value.

Once the temperature set point has been investigated, return the temperature set point to its original value.

PID Settings and optimisation

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Begin with the process vessel set up as described at the start of this laboratory sheet. If the apparatus has been used recently before this section of the exercise it will be necessary to cool the water in the process vessel before beginning this section. This may be speeded up by passing cold water through the heating/cooling coil by setting the PSV to 100%, as for investigating disturbances. Return the PSV setting to 0% after cooling the water to 30 °C or less.

Create a new results sheet by selecting the icon in the tool bar of the software.

Set the software to provide On/Off control (set P to 0%).

Set the temperature set point to 40 °C (this allows room for overshoot during the initial tuning process).

Select the icon to begin data logging.

Wait as the temperature rises to the set point and overshoots. Continue logging as the controller switches off the heater and the water cools. Continue logging until the controller switches on the heater and the temperature begins to rise once more, then select the icon to finish data logging. The cooling process will take some time, as the water cools slowly. DO NOT increase the cooling rate by passing cold water through the coil.

Plot a graph of time against water temperature.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

$I = t$

$D = t / 6$

Set these values in the software.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to use cold water in the heating coil to accelerate the cooling process.

Create a new results sheet by selecting the icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 15 minutes is suggested.

Select the icon to finish data logging.

From these new results, plot a graph of temperature T1 against time and observe the shape of the graph.

If the figure for Proportional Band obtained by this method is very small (less than 5%), and the Integral Time very large (more than 30s) then the method chosen for finding approximate tuning values may not be suitable and the best value for Proportional Band may be greater than 100%.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the vessel to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

Set the Proportional Band to 200%, the Integral Time to 60s and the Derivative Time to 0s.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the 

icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 15 minutes is suggested.

Select the 

icon to finish data logging.

Plot a graph of temperature T1 against time and compare the shape of the graph to that obtained using the values obtained from the On/Off control graph.

If a Proportional Band of greater than 100% gives less oscillation and overshoot than the previous settings, leave the PID values as they are.

Proportional control sets the band within which the controller will vary time the heater spends on and off. Outside this band the heater will be always on or always off. If a slow response is observed, or large oscillations occur in temperature, after changing the value of P then reduce the value. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of P to the basic value obtained from the initial measurements.

Integral control can be adjusted to reduce offset in the temperature. If a significant offset is observed after changing the value of I, reduce the value. Investigate the results of any change by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme after changing the value of D, reduce the value. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the temperature over time as it rises from a low value. Compare this to the initial graph.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise P).

Each set of data not already graphed as part of the procedure should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level control exercises have already been performed, compare the ease of optimisation for temperature control with the optimisations for PID level control. Compare the results obtained using PID temperature control against those using a simple on/off controller (as in Exercise N) and time proportioning control (Exercise O). Discuss the suitability of PID control for regulating process temperature.

Exercise Q: Manual control of heater power

Objective

To control the temperature in a process vessel manually by controlling power to a heating element.

Overview

The temperature within the process vessel is monitored using a thermocouple type sensor. A low, continuous flow of water is passed through the vessel. By manually switching the power to a heating element on or off, the temperature within the vessel is regulated to maintain the required set point.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to the upper fitting on the side of the small process vessel. Ensure that the lower fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 6: Temperature Control (direct continuous heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Select a second length of tubing with a self-sealing fitting on one end and an open end at the other, and direct the open end to a suitable drain. Connect the quick-release fitting to the lower connection on the side of the small process vessel. Water will drain from the free end. Half close the drain valve on the end of the tube.

In the software, increase the PSV value using the arrow keys until the water level in the process vessel is stable and covers the coil. Adjust the drain valve so that the water level in the vessel remains constant and covers the coil at a PSV setting of approximately 50%. The apparatus should not be left unattended, to ensure the process vessel does not overflow or run dry.

Procedure

SAFETY NOTE: During this exercise, the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Check that the temperature reading T1 is a sensible value (usually between 5 and 30 degrees Celsius depending on mains water temperature).

Select 'Configure' from the Sample menu, and set sampling to Automatic at intervals of 30 seconds, with duration as Continuous.

The heating element is switched on and off manually using the switch on the software screen. Switch on the heater, and observe the temperature T1. Check that this rises as the heater operates. Switch off the heater again.

Heating Characteristics in Continuous Operation

The temperature in the vessel may be manually controlled by switching the power to the heating element off and on. By switching the heater on and off using the switch on the software screen raise the temperature of the water in the vessel to 30 °C and maintain this temperature by powering the heater off and on. Note the control actions required to maintain a constant temperature within the water flowing through the vessel. Record any differences between the time required for the water to rise and fall in temperature. Note any time lag between applying a control action and observing its effect.

(**Note:** if the mains water temperature is very high- approaching or exceeding 30 °C- then 40 °C may be used as a Set Point value instead).

Select the  icon to begin data logging.

Maintain the temperature in the vessel, using manual control, for five minutes.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

Select the  icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Note the control action required to maintain the temperature within the vessel at the new flow rate.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to control the temperature, noting the action required.

Set the PSV back to its original setting, close the drain valve, and continue to control the temperature within the vessel.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Disturbances’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise Q).

Each set of data should be plotted on a graph of temperature T1 against time.

Write up your experiment, commenting on the heating and cooling characteristics of continuous operation and the actions required for manual control of the heating process. Give reasons for any time delay between applying a control action and observing a response. Explain any difference between heating and cooling rate. Give examples of industrial control situations in which a step change in flow rate might occur.

Exercise R: Thermostat control of Heater Power

Objective

To control the temperature in a process vessel using a thermostat to control a heating element.

Overview

The required Set Point temperature within the process vessel is set on a simple thermostat-type controller. The temperature within the process vessel is monitored by the probe of the thermostat. The thermostat then switches a heating element on or off to maintain the required set point temperature within the vessel.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Switch on mains power to the apparatus.

Run the PCT40 software and select ‘Section 6: Temperature Control (direct continuous heating)’.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to the upper fitting on the side of the small process vessel. Ensure that the lower fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Select a second length of tubing with a self-sealing fitting on one end and an open end at the other, and direct the open end to a suitable drain. Connect the quick-release fitting to the lower connection on the side of the small process vessel. Water will drain from the free end. Half close the drain valve on the end of the tube.

In the software, increase the PSV value using the arrow keys until the water level in the process vessel is stable and covers the coil. Adjust the drain valve so that the water level in the vessel remains constant and covers the coil at a PSV setting of approximately 50%. The apparatus should not be left unattended, to ensure the process vessel does not overflow or run dry.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Set the temperature at which the thermostat will operate. The Set Point is set by rotating the dial on top of the thermostat mounted in the lid of the small process vessel. The dial is turned until the arrow on the dial points at the required Set Point. A recommended starting value is 30 degrees Celsius. If the local mains water temperature is close to 30 °C then a higher value may be used: at least 10 °C greater than the mains supply is recommended.

Check that the temperature reading T1 is a sensible value (usually between 5 and 30 degrees Celsius depending on mains water temperature).

Set data logging to automatic at intervals of 30 seconds with continuous duration.

Select the GO icon to begin data logging.

Note the behaviour of the heating element as the temperature approaches the set point. It is possible to observe heated water rising from the heating element when the power is on. The heater also responds audibly when power is switched on or off. Additionally, the switch for the heater is displayed on the mimic diagram screen within the software, allowing observation of the heater action.

The change in temperature may be most easily observed using the graph screen in the software. If the graph does not appear automatically when the graph screen is selected, select ‘T1’ for the Y axis and ‘Time’ for the x-axis, then plot the graph. New points will be added as they are logged.

Continue logging for 10 minutes. Select the STOP icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

Select the GO icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 10 minutes.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to log the temperature for another 10 minutes, and then select the STOP icon to finish data logging.

Set the PSV back to its original setting and close the drain valve.

Temperature Set Point

Investigate the effect of changing the temperature at which the on/off heater switch operates:

Select the icon to create a new results sheet.

On top of the thermostat, alter the temperature set point to 40 °C (or to 10 °C higher than the initial set point value if an initial value of 30 °C was not used).

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in temperature until the oscillations reach stable values. Suggested values for the temperature set point value are 50, 60 and 70 °C. Remember to create a new results sheet for each set of data. Note that there is a power cut-out built in to the heating circuit as a safety feature, which operates if the temperature of the water in the vessel exceeds approximately 80°C. Set Point values should therefore be chosen that are significantly lower than 80°C.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow Rate’, ‘Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise R).

Each set of data should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations for which a simple on/off controller would be suitable.

Exercise S: Temperature input with on/off control

Objective

To control the temperature in a process vessel using an on/off controller connected to a temperature sensor, by controlling power to a heating element.

Overview

The temperature within the process vessel is monitored using a thermocouple type sensor. The output is sent to an On/Off controller that switches a heating element on or off to maintain the required set point temperature within the vessel.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Switch on mains power to the apparatus.

Run the PCT40 software and select 'Section 6: Temperature Control (direct continuous heating)'.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to the upper fitting on the side of the small process vessel. Ensure that the lower fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Select a second length of tubing with a self-sealing fitting on one end and an open end at the other, and direct the open end to a suitable drain. Connect the quick-release fitting to the lower connection on the side of the small process vessel. Water will drain from the free end. Half close the drain valve on the end of the tube.

In the software, increase the PSV value using the arrow keys until the water level in the process vessel is stable and covers the coil. Adjust the drain valve so that the water level in the vessel remains constant and covers the coil at a PSV setting of approximately 50%. The apparatus should not be left unattended, to ensure the process vessel does not overflow or run dry.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Setting the On/Off Controller

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale.

Set the temperature at which the on/off controller will operate. A recommended starting value is 30 degrees Celsius. Check that the temperature reading T1 is a sensible value (usually between 5 and 30 degrees Celsius depending on mains water temperature). A higher Set Point temperature will be required if the mains water inlet supply temperature is close to 30 °C: a value of at least 10 degrees higher than the inlet supply is recommended.

Apply the settings and close the controller window.

From the Sample menu at the top of the screen, select Configure… and set data logging to automatic at intervals of thirty seconds.

Select the  icon to begin data logging.

Note the behaviour of the heating element as the temperature approaches the set point. It is possible to observe heated water rising from the heating element when the power is on. The heater also responds audibly when power is switched on or off. Additionally, the switch for the heater is displayed on the mimic diagram screen within the software, allowing observation of the heater action.

The change in temperature may be most easily observed using the graph screen in the software. If the graph does not appear automatically when the graph screen is selected, select ‘T1’ for the Y axis and ‘Time’ for the x-axis, then plot the graph. New points will be added as they are logged.

Continue logging for 10 minutes. Select the  icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the  icon to create a new results sheet.

Select the  icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 10 minutes.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to log the temperature for another 10 minutes, and then select the icon to finish data logging.

Set the PSV back to its original setting and close the drain valve.

Temperature Set Point

Investigate the effect of changing the temperature at which the on/off heater switch operates:

Select the icon to create a new results sheet.

In the software, alter the temperature set point to 40 °C.

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in temperature until the oscillations reach stable values. Suggested values for the temperature set point value are 50, 60 and 70 °C. Remember to create a new results sheet for each set of data. Note that the heater circuit includes a safety cut-out that will shut off power to the heater if the temperature of the process vessel reaches approximately 80 °C. Set point values should therefore be kept below this temperature.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. 'Flow Rate', 'Set Point', etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise S).

Each set of data should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response.

Give examples of industrial control situations for which a simple on/off controller would be suitable.

Exercise T: Temperature input with time proportional control

Objective

To control the temperature in the process vessel using a time-proportional controller connected to a temperature sensor, with a heating element raising the temperature of the fluid within the vessel.

Overview

The control system in this exercise consists of a temperature sensor with an output proportional to the temperature detected by the sensor. The output is sent to a time proportional controller which switches the power supply to the heating element on or off. The time proportioning controller turns the output on and off at intervals. This ratio of time “on” to time “off” may be set manually, or may be set automatically by the controller which then varies the ratio according to the difference between the current control variable and the required Set Point value.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The PC should be connected to a suitable PC on which the PCT40 software has been installed using the grey USB cable supplied.

Switch on mains power to the apparatus.

Run the PCT40 software and select ‘Section 6: Temperature Control (direct continuous heating)’.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to the upper fitting on the side of the small process vessel. Ensure that the lower fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Select a second length of tubing with a self-sealing fitting on one end and an open end at the other, and direct the open end to a suitable drain. Connect the quick-release fitting to the lower connection on the side of the small process vessel. Water will drain from the free end. Half close the drain valve on the end of the tube.

In the software, increase the PSV value using the arrow keys until the water level in the process vessel is stable and covers the coil. Adjust the drain valve so that the water level in the vessel remains constant and covers the coil at a PSV setting of approximately 50%. The apparatus should not be left unattended, to ensure the process vessel does not overflow or run dry.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Run the PCT40 software. Select ‘Configure’ from the Sample menu and set sampling to Automatic with sample intervals of 30 seconds and a duration of Continuous.

Fixed (manually set) ratio

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set P, I and D to 0.

In Manual Control set the percentage time during which the heater will be on. 50% is suggested as a starting value

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 50% and a cycle time of 10s, the heater will be switched on for 5s and switched off for 5s).

Select the Manual Control radio button and click on ‘Apply’. The heater should begin to operate intermittently as the time proportional controller sends signals to control it.

Check that there is a new data sheet for data logging.

Select the  icon to begin data logging, and observe the temperature in the vessel, T1. When the temperature has changed by more than 20 °C, select the  icon to finish data logging.

Adjust the control percentage according to the change in temperature. If the change was rapid, reduce the setting by 25 to 30%. If it was gradual, reduce the value by 10 or 15%.

Continue to monitor the temperature and adjust the percentage value until the temperature maintains a constant level.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Select the  icon to begin data logging, and log the temperature T1 for a few minutes. Select the  icon to finish data logging.

Make a note of the settings used.

Open the controller window and set Mode of Operation to Off.

Set the PSV to 100%, allowing cold water to flow through the coil in the small process vessel. When the temperature T1 has reduced to around 20 – 30 °C, set the PSV back to 0%.

Create a new results sheet by selecting the icon in the tool bar of the software.

Controller-controlled time proportioning

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Set Point to 30 °C (If the mains water temperature is close to 30 °C then a higher Set Point should be chosen, e.g. 40 °C).

Set P to 100%.

Leave I and D set to 0.

The Manual Control setting may be ignored.

Leave the Cycle Time at 10s.

Select the Automatic Control radio button and click on ‘Apply’. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the icon to begin data logging, and observe the temperature in the process vessel. Note the behaviour of the heater as the temperature approaches the Set Point. When the oscillations around the Set Point have settled, select the icon to finish data logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

Select the icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 10 minutes.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to log the temperature for another 10 minutes, and then select the icon to finish data logging.

Set the PSV back to its original setting and close the drain valve.

Temperature Set Point

Investigate the effect of changing the temperature at which the on/off heater switch operates:

Create a new results sheet by selecting the icon.

In the software, alter the temperature set point to 40 °C (or ten degrees higher than the original set point temperature if a value other than 30 °C was selected).

Select the icon to begin data logging.

Log the temperature for 10 minutes, then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 50 and 60 °C, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data. Note that there is a safety cutout in the heater circuit that will switch off the heater if the temperature in the vessel exceeds approximately 80 °C. Set Point values should therefore be kept well below this temperature.

Return the temperature set point to its original value.

Cycle Time

Create a new results sheet by selecting the icon in the tool bar of the software.

In the software, set the cycle time to 5s.

Select the icon to begin data logging.

Log the temperature in the vessel for 10 minutes, and then select the icon to finish data logging.

Alter the cycle time again, to 20s.

Select the icon to begin data logging.

Log the temperature in the vessel for 15 minutes, and then select the icon to finish data logging.

Reset the cycle time to 10s.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow rate’, ‘Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise T).

Each set of data should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Compare the results obtained using time proportional control against those using a simple on/off controller (as in Exercise Q).

Suggest industrial applications in which step-changes in flow rate might be experienced. Discuss the suitability of time-proportional control for those applications.

Exercise U: Proportional temperature input with PID control

Objective

To control the temperature in the process vessel with PID control of a heating element, using a temperature sensor to monitor the temperature.

Overview

As for time proportional control, the temperature sensor sends a signal to the controller that varies with the temperature of the sensor. The controller sends a signal to the heater that is proportional to the signal from the sensor. The heater power may only be on or off, so the controller varies the time for which power is supplied to the heater.

PID control adds two extra control parameters, Integral and Derivative, which may already have been investigated in the Level Control exercises:

With proportional control action, the controller produces a signal that is proportional to the error (the difference between the monitored variable and the set point value). This creates an offset between setpoint value and actual value (the controller only supplies an output when there is an error, so there is no controller output when the value is not at the set point). It also generates an overshoot (the system will oscillate above and below the setpoint value at the start of the control period until stability is attained).

With integral control action, the controller gives an output that is proportional to the time integral of the error. Integral control action can potentially be used alone to control a process, but is normally used in conjunction with proportional action. When used with proportional action it can eliminate offset. It can also cause higher maximum deviation and a longer response time than with proportional action alone.

With derivative control action, the controller gives an output that is proportional to the derivative of the rate of change of the error. The output is related only to the rate of change, not to the magnitude of the error. Derivative control action cannot be used alone, but must be combined with another action such as proportional control action. When used with proportional action, derivative control can eliminate excessive oscillation. It cannot eliminate offset errors inherent in proportional action

Proportional, integral and derivative control actions may be combined to eliminate offset, reduce maximum deviation and minimise the frequency of oscillation. Finding the optimum values of P, I and D for a particular process is often referred to as *tuning* or *optimisation*.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC which has the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to the upper fitting on the side of the small process vessel. Ensure that the lower fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 6: Temperature Control (direct continuous heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Select a second length of tubing with a self-sealing fitting on one end and an open end at the other, and direct the open end to a suitable drain. Connect the quick-release fitting to the lower connection on the side of the small process vessel. Water will drain from the free end. Half close the drain valve on the end of the tube.

In the software, increase the PSV value using the arrow keys until the water level in the process vessel is stable and covers the coil. Adjust the drain valve so that the water level in the vessel remains constant and covers the coil at a PSV setting of approximately 50%. The apparatus should not be left unattended, to ensure the process vessel does not overflow or run dry.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

In the PCT40 software, enter a set point value for the temperature of 30 degrees centigrade. If the temperature of the local mains water supply is close to 30 °C then a higher set point value may be chosen, such as 40 °C.

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are Proportional Band (P) of 100%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

Select ‘Configure...’ from the Sample menu. Set the software to Automatic logging, with a sample interval of 10 seconds and Continuous duration.

Select the 

icon to begin data logging.

Log the temperature within the vessel for 10 minutes, then select the 

icon to stop logging.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

Select the icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 10 minutes.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to log the temperature for another 10 minutes, and then select the icon to finish data logging.

Set the PSV back to its original setting and close the drain valve.

Temperature Set Point

Investigate the effect of changing the set point temperature:

Create a new results sheet by selecting the icon.

In the software, alter the temperature set point to 40 °C. If the initial Set Point was not 30 °C then a value 10 °C higher than the initial value should be used instead.

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 50 and 60 °C, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data. Note that the heater circuit includes a safety cut-out that will shut off power to the heater if the temperature in the process vessel exceeds approximately 80 °C. For this reason set point values should be kept well below this temperature.

Return the temperature set point to its original value.

PID Settings and optimisation

To begin tuning it is necessary to set initial values, which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Begin with the process vessel set up as described at the start of this laboratory sheet. If the apparatus has been used recently before this section of the exercise, it will be necessary to cool the water in the process vessel before beginning this section. This may be speeded up by increasing the flow rate through the vessel. Fully open the drain valve in the base of the vessel, and increase the PSV setting to maintain the fluid level. Close the drain and return the PSV to its previous setting after cooling the water to 30 °C or less.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Set the software to provide On/Off control (set P to 0%).

Set the temperature set point to 40 °C (this allows room for overshoot during the initial tuning process).

Select the  icon to begin data logging.

Wait as the temperature rises to the set point and overshoots. Continue logging as the controller switches off the heater and the water cools. Continue logging until the controller switches on the heater and the temperature begins to rise once more, then select the  icon to finish data logging. This process will take some time, as the water cools slowly.

Plot a graph of time against water temperature.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

P = y / 3

I = t

D = t / 6

Set these values in the software.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the vessel to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the  icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 10 minutes is suggested.

Select the  icon to finish data logging.

From these new results, plot a graph of Temperature T1 against time and observe the shape of the graph.

If the figure for Proportional Band obtained by this method is very small (less than 5%), and the Integral Time very large (more than 30s) then the method chosen for finding approximate tuning values may not be suitable and the best value for Proportional Band may be greater than 100%.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the vessel to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

Set the Proportional Band to 200%, the Integral Time to 60s and the Derivative Time to 0s.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the 

icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 10 minutes is suggested.

Select the 

icon to finish data logging.

Plot a graph of temperature T1 against time and compare the shape of the graph to that obtained using the values obtained from the On/Off control graph.

If a Proportional Band of greater than 100% gives less oscillation and overshoot than the previous settings, leave the PID values as they are.

Proportional control sets the band within which the controller will vary time the heater spends on and off. Outside this band the heater will be always on or always off. If a slow response is observed, or large oscillations occur in temperature, reduce the value of P. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of P to the basic value obtained from the initial measurements.

Integral control can be adjusted to reduce offset in the temperature. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme, reduce the value of D. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the temperature over time as it rises from a low value. Compare this to the initial graph.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow Rate’, ‘Integral Setting’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise U).

Each set of data not already graphed as part of the procedure should be plotted on a graph of temperature T1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level control exercises have already been performed, compare the ease of optimisation for temperature control with the optimisations for PID level control. Compare the results obtained using PID temperature control against those using a simple on/off controller (as in Exercise Q) and time proportioning control (Exercise T). Discuss the suitability of PID control for regulating process temperature.

Exercise V: Manual control of heater power

Objective

To manually control the temperature the fluid passing through a coil that passes through fluid within a process vessel, by controlling power to a heating element heating the fluid within the vessel.

Overview

The temperatures within the process vessel and coil are monitored using thermocouple type sensors. A continuous flow of water is passed through the coil within the vessel. The water within the vessel is heated by a heating element, and heat is transferred to the water within the coil. By manually switching the power to the heating element on or off, the temperature is regulated to maintain the required set point.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 7: Temperature Control (indirect heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the PSV and connect it to one side of the gear pump.

Using another length of tube with quick release fittings at both ends, connect the other socket on the side of the small process vessel to the other side of the gear pump.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the quick-release fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and an open end at the other. Connect the quick release fitting to the other side of the coil, and direct the opposite end of the tube to a suitable drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise, the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Switch on mains power to the console and run the PCT40 software.

Check that the temperature readings T1, T2 and T3 are giving sensible values (usually between 5 and 30 degrees Celsius depending on mains water temperature).

The heating element is switched on and off manually using the switch on the software screen. Switch on the heater, and observe the temperature T1. Check that this rises as the heater operates. Switch off the heater again.

Select 'Configure...' from the Sample menu and set data logging to Automatic with a sample interval of 10 seconds and Continuous duration.

Heating Characteristics in Continuous Operation

The temperature in the vessel may be manually controlled by switching the power to the heating element off and on. By switching the heater on and off using the switch on the software screen raise the temperature of the water in the vessel to 30 °C and maintain this temperature by powering the heater off and on. Note the control actions required to maintain a constant temperature within the water flowing through the vessel. Record any differences between the time required for the water to rise and fall in temperature. Note any time lag between applying a control action and observing its effect.

Select the  icon to begin data logging.

Control the temperature manually for five minutes.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

The water in the small process vessel may be circulated (stirred or mixed) using the gear pump. Set the gear pump to 50% and repeat the procedure in the paragraph above, noting any difference in response between the system with and without the gear pump in operation.

Select the  icon to begin data logging.

Control the temperature manually for five minutes.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Set the gear pump back to 0%.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the coil:

Select the  icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Note the control action required to maintain the temperature within the vessel at the new flow rate.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to control the temperature, noting the action required.

Set the PSV back to its original setting, close the drain valve, and continue to control the temperature within the vessel.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Set the gear pump to 50% to circulate the hot water within the vessel, select the  icon to begin data logging, and repeat the investigation of the effect of disturbances.

Select the  icon to finish data logging.

Create a new results sheet by selecting the  icon.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Disturbances’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise V).

Each set of data should be plotted on a graph of temperature T3 against time.

Write up your experiment, commenting on the heating and cooling characteristics of continuous operation and the actions required for manual control of the heating process. Give reasons for any time delay between applying a control action and observing a response. Explain any difference between heating and cooling rate. Comment on the effect of stirring. Give examples of industrial control situations in which a step change in flow rate might occur.

Exercise W: Temperature input with on/off control

Objective

To control the temperature of water flowing through a coil within a process vessel using an on/off thermostat.

Overview

The temperature within the process vessel is monitored using a thermocouple type sensor. The computer software sends a signal to the heater depending on whether the temperature is above or below the Set Point temperature. The fluid within the vessel in turn heats fluid flowing through a coil within the vessel.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 7: Temperature Control (indirect heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the PSV and connect it to one side of the gear pump.

Using another length of tube with quick release fittings at both ends, connect the other socket on the side of the small process vessel to the other side of the gear pump.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the quick-release fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and an open end at the other. Connect the quick release fitting to the other side of the coil, and direct the opposite end of the tube to a suitable drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Switch on mains power to the console and run the PCT40 software.

Check that the temperature readings T1, T2 and T3 are giving sensible values (usually between 5 and 30 degrees Celsius depending on mains water temperature).

Select 'Configure...' from the Sample menu and set data logging to Automatic with a sample interval of 10 seconds and Continuous duration.

Setting the On/Off Controller

In the PCT40 software, select 'Control' to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale.

In the software PID controls, set the Set Point temperature for fluid leaving the coil in the process vessel. 50°C is suggested as a suitable value. 30°C is suggested, unless the local water supply is close to this temperature when a higher value may be selected. Values of greater than 50°C will be difficult or impossible to achieve using indirect heating.

Apply the settings and close the controller window.

Select the  icon to begin data logging.

Note the behaviour of the heating element as the temperature approaches the set point. It is possible to observe heated water rising from the heating element when the power is on. The heater also responds audibly when power is switched on or off. Additionally, the switch for the heater is displayed on the mimic diagram screen within the software, allowing observation of the heater action. An indicator light on the software screen also indicates whether the thermostat is on (sending a signal to the heater) or off (sending no signal to the heater).

The change in temperature may be most easily observed using the graph screen in the software. If the graph does not appear automatically when the graph screen is selected, select 'T3' for the Y axis and 'Time' for the x-axis, then plot the graph. New points will be added as they are logged.

Continue logging for 10 minutes. Select the  icon to finish data logging.

Select the  icon to create a new results sheet.

Set the gear pump to 50% to circulate water through the process vessel, and then repeat the procedure above.

Return the gear pump setting to 0%.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

Select the icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 10 minutes.

Select the icon to finish data logging.

Plot a graph of T3 against time, as before, and modify the thermostat setting as before. Make further data logging runs as before until T3 is maintained at or near the desired Set Point value. Remember to select a new results sheet before each data logging run.

Set the gear pump to 50% to circulate and mix the water in the process vessel, and repeat the investigation of disturbances.

If time allows, make a further adjustment of 20% in the PSV setting, and adjust the thermostat to maintain the temperature of T3. Note whether it is possible to maintain the original Set Point at this increased flow rate.

Return the settings for the PSV and the thermostat to their original values.

Temperature Set Point

Investigate the effect of changing the temperature set point for T3:

Select the icon to create a new results sheet.

Choose a new Set Point value for T3. 40°C is suggested, unless this was the initial value chosen, when 50°C may be used instead.

Using the previous data gathered as a reference, adjust the temperature set point on top of the thermostat in a way that should produce the desired change in T3.

Select the icon to begin data logging.

Log the temperature for 5 minutes, and then select the icon to finish data logging.

Select the icon to create a new results sheet.

Repeat the procedure, altering the set point and logging the change in temperature, until the temperature T3 can be maintained at or near the desired value. Remember to create a new results sheet for each set of data.

Note that there is a safety temperature cutout set to switch off the heating element if the water temperature exceeds approximately 80°C. This will override any other heater controls. It is suggested that thermostat Set Points close to or above 80°C are avoided.

Repeat the investigation of Set Point with the gear pump set to 50%.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow Rate’, ‘Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise W).

Each set of data should be plotted on a graph of temperature T3 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the effect mixing (using the gear pump) has on the results.

Give examples of industrial control situations for which a simple on/off controller would be suitable.

Exercise X: Temperature input with time proportional control

Objective

To control the temperature of water within a coil that passes through a process vessel filled with water, using a time-proportional controller connected to a temperature sensor, with a heating element raising the temperature of the fluid within the vessel and therefore the temperature of fluid within a coil passing through the vessel.

Overview

A time proportional controller is a form of on/off controller. The controller can be set to vary the proportion of time ‘off’ to time ‘on’ over a set timescale or cycle time. By varying the time proportion for which the heater is on, the temperature of the water within the vessel (and therefore within the coil) can be maintained at the required Set Point.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 7: Temperature Control (indirect heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the PSV and connect it to one side of the gear pump.

Using another length of tube with quick release fittings at both ends, connect the other socket on the side of the small process vessel to the other side of the gear pump.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the quick-release fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and an open end at the other. Connect the quick release fitting to the other side of the coil, and direct the opposite end of the tube to a suitable drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Run the PCT40 software.

Select ‘Configure...’ from the ‘Sample’ menu, and set the software to Automatic sampling with a sample interval of 10 seconds and Continuous duration.

Setting the On/Off Controller

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Proportional Band (P) to 0%, the Integral Time (I) to 0s and the Derivative Time (D) to 0s. The controller is now set as a simple On/Off controller with fixed hysteresis of 0.5% of full scale. Select ‘Apply’ and close the control window.

Set the PSV to 20% to give a low flow rate through the coil in the small process vessel.

Fixed (manually set) ratio

In the PCT40 software, select ‘Control’ to open the PID controller window.

In Manual Control set the percentage time during which the heater will be on. 20% is suggested as a starting value

At the bottom left, set the Cycle Time to 10s- this is the time over which the control percentage will be applied (i.e. for a percentage of 20% and a cycle time of 10s, the heater will be switched on for 2s and switched off for 8s).

Select the Manual Control radio button and click on ‘Apply’. The heater should begin to operate intermittently as the time proportional controller sends signals to control it.

Check that there is a new data sheet for data logging.

Select the GO icon to begin data logging, and observe the temperature of the fluid leaving the coil, T3. When the temperature has changed by more than 10 °C, select the STOP icon to finish data logging.

Adjust the control percentage according to the change in temperature. If the change was rapid, reduce the setting by 5 to 10%. If it was gradual, reduce the value by 2 or 3%.

Continue to monitor the temperature and adjust the percentage value until the temperature maintains a constant level.

When you have finished, continue logging the steady value for a further 2 minutes, then select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Controller-controlled time proportioning

In the PCT40 software, select ‘Control’ to open the PID controller window.

Set the Set Point to 30 °C (if local mains water supply is close to 30 °C then a higher Set Point value should be selected. 10 °C higher than the mains water temperature is recommended).

Leave the PID settings and the Cycle Time unchanged.

Select the Automatic Control radio button and click on ‘Apply’. The valve should begin to operate intermittently as the time proportional controller sends signals to control it.

Select the icon to begin data logging, and observe the temperature T3. Note the behaviour of the heater as the temperature approaches the Set Point. When the oscillations around the Set Point have settled, select the icon to finish data logging.

In the graph screen of the software, plot a graph of temperature T3 against time. New plots will be added automatically as the software records them.

Log the temperature within the vessel for 10 minutes, then select the icon to stop logging.

Select the icon to create a new results sheet.

Effect of stirring

Set the PSV to 100%, allowing cold water to flow through the coil in the small process vessel. When the temperature T1 has reduced to around 20 – 30 °C, set the PSV back to 20%.

Set the Hot Pump to a speed of 50% to circulate (stir or mix) the water in the process vessel.

Select the icon to begin data logging.

Log the temperature within the vessel for 10 minutes, then select the icon to stop logging.

Return the gear pump setting to 0%.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

In the software, increase the PSV setting to 40%.

Select the icon to begin data logging. Continue to log the temperature for another 10 minutes, and then select the icon to finish data logging.

If there is time, increase the PSV setting to 60%, and repeat this section of the exercise.

Set the PSV back to 20%.

Create a new results sheet and repeat the investigation of disturbances with the gear pump set to a speed of 50% to circulate (stir or mix) the water in the process vessel. Return the gear pump setting to 0%.

Temperature Set Point

Investigate the effect of changing the set point temperature for T3:

Create a new results sheet by selecting the icon.

Choose a new Set Point value. 40°C is suggested, unless this was the original value. Depending on the starting temperature of the water, it may not be possible to achieve temperatures above 50°C during indirect heating.

Select the icon to begin data logging.

Log the temperature for 10 minutes, then select the icon to finish data logging.

Create a new results sheet, and repeat the investigation of set point change with the gear pump set to a speed of 50%. Return the gear pump setting to 0%.

Cycle Time

Create a new results sheet by selecting the icon in the tool bar of the software.

In the software, set the cycle time to 5s.

Select the icon to begin data logging.

Log the temperature in the vessel for 10 minutes, and then select the icon to finish data logging.

Alter the cycle time again, to 20s.

Select the icon to begin data logging.

Log the temperature in the vessel for 10 minutes, and then select the icon to finish data logging.

Reset the cycle time to 10s.

Create a new results sheet, and repeat the investigation of cycle time with the gear pump set to a speed of 50%.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow rate’, ‘Cycle Time’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise X).

Each set of data should be plotted on a graph of temperature T3 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Compare the results obtained using time proportional control against those using a simple on/off controller (as in Exercise W). Comment on the effect of stirring.

Describe the effect of cycle time on an indirect temperature control system.

Suggest industrial applications in which step-changes in flow rate might be experienced. Discuss the suitability of time-proportional control for those applications.

Exercise Y: Proportional temperature input with PID control

Objective

To control the temperature in the process vessel with PID control of a heating element, using a temperature sensor to monitor the temperature.

Overview

As for time proportional control, the temperature sensor sends a signal to the controller that varies with the temperature of the sensor. The controller sends a signal to the heater that is proportional to the signal from the sensor. The heater power may only be on or off, so the controller varies the time for which power is supplied to the heater.

PID control adds two extra control parameters, Integral and Derivative, which may already have been investigated in previous exercises:

With proportional control action, the controller produces a signal that is proportional to the error (the difference between the monitored variable and the set point value). This creates an offset between setpoint value and actual value (the controller only supplies an output when there is an error, so there is no controller output when the value is not at the set point). It also generates an overshoot (the system will oscillate above and below the setpoint value at the start of the control period until stability is attained).

With integral control action, the controller gives an output that is proportional to the time integral of the error. Integral control action can potentially be used alone to control a process, but is normally used in conjunction with proportional action. When used with proportional action it can eliminate offset. It can also cause higher maximum deviation and a longer response time than with proportional action alone.

With derivative control action, the controller gives an output that is proportional to the derivative of the rate of change of the error. The output is related only to the rate of change, not to the magnitude of the error. Derivative control action cannot be used alone, but must be combined with another action such as proportional control action. When used with proportional action, derivative control can eliminate excessive oscillation. It cannot eliminate offset errors inherent in proportional action

Proportional, integral and derivative control actions may be combined to eliminate offset, reduce maximum deviation and minimise the frequency of oscillation. Finding the optimum values of P, I and D for a particular process is often referred to as *tuning* or *optimisation*.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable provided.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the PSV to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 7: Temperature Control (indirect heating)’.

In the software, set the PSV to 100% and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then set the PSV to 0%.

Disconnect the tube from the PSV and connect it to one side of the gear pump.

Using another length of tube with quick release fittings at both ends, connect the other socket on the side of the small process vessel to the other side of the gear pump.

Take a length of tube with a quick release fitting at one end and a Guest push fitting at the other. Connect one end to the PSV and the other end to the coil inside the small process vessel (via the quick-release fitting mounted on the lid).

Take a second length of tube with a quick-release fitting at one end and an open end at the other. Connect the quick release fitting to the other side of the coil, and direct the opposite end of the tube to a suitable drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

SAFETY NOTE: During this exercise, the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

In the PCT40 software, enter a set point value for the temperature of 30 degrees centigrade, unless the local water temperature is close to this value when 40°C may be chosen instead.

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are Proportional Band (P) of 100%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

Set the software to automatic logging at intervals of 10 seconds with continuous duration.

Select the 

icon to begin data logging.

Log the temperature within the vessel for 10 minutes, then select the 

icon to stop logging.

Create a new results sheet and repeat the procedure with the gear pump set to a speed of 50% to circulate (stir or mix) the water in the process vessel. Return the gear pump setting to 0%.

Disturbances

Within the software it is possible to introduce disturbances in the temperature inside the process vessel by changing the flowrate of water through the vessel:

In the software, select the icon to create a new results sheet.

Select the icon to begin data logging.

In the software, increase the PSV setting by 20%. Open the drain valve at the base of the process vessel enough to balance the flow in and out of the vessel, so that the fluid level in the vessel remains constant.

Log the temperature for 5 minutes.

Increase the PSV setting by a further 20%, and open the drain valve more to maintain the fluid level within the vessel.

Continue to log the temperature for another 5 minutes, and then select the icon to finish data logging.

Set the PSV back to its original setting and close the drain valve.

Create a new results sheet and repeat the investigation of disturbances with the gear pump set to a speed of 50% to circulate (stir or mix) the water in the process vessel. Return the gear pump setting to 0%.

Temperature Set Point

Investigate the effect of changing the set point temperature:

Create a new results sheet by selecting the icon.

In the software, alter the temperature set point to 40 °C.

Select the icon to begin data logging.

Log the temperature for 5 minutes, and then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 45 and 50 °C. Depending on the starting temperature of the water, it may not be possible to achieve temperatures above 50°C during indirect heating.

Return the temperature set point to its original value.

Create a new results sheet and repeat the investigation of set point change with the gear pump set to a speed of 50% to circulate (stir or mix) the water in the process vessel. Return the gear pump setting to 0%.

PID Settings and Optimisation

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Begin with the process vessel set up as described at the start of this laboratory sheet. If the apparatus has been used recently before this section of the exercise it will be necessary to cool the water in the process vessel before beginning this section. This may be speeded up by increasing the flow rate through the vessel. Fully open the drain valve in the base of the vessel, and increase the PSV setting to maintain the fluid level. Close the drain and return the PSV to its previous setting after cooling the water to 30 °C or less.

Create a new results sheet by selecting the icon in the tool bar of the software.

Set the software to provide On/Off control (set P to 0%).

Set the temperature set point to 40 °C (this allows for overshoot during the initial tuning process).

Select the icon to begin data logging.

Wait as the temperature rises to the set point and overshoots. Continue logging as the controller switches off the heater and the water cools. Continue logging until the controller switches on the heater and the temperature begins to rise once more, then select the icon to finish data logging. This process will take some time, as the water cools slowly.

Plot a graph of time against water temperature.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

$I = t$

$D = t / 6$

Set these values in the software.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the vessel to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

Create a new results sheet by selecting the icon in the tool bar of the software.

Return the temperature set point to 45 °C

Select the  icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 30 minutes is suggested.

Select the  icon to finish data logging.

From these new results, plot a graph of temperature T1 against time and observe the shape of the graph.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the vessel to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

If the figure for Proportional Band obtained by this method is very small (less than 5%), and the Integral Time very large (more than 30s) then the method chosen for finding approximate tuning values may not be suitable and the best value for Proportional Band may be greater than 100%.

Set the Proportional Band to 200%, the Integral Time to 60s and the Derivative Time to 0s.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the  icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 10 minutes is suggested.

Select the  icon to finish data logging.

Plot a graph of temperature against time and compare the shape of the graph to that obtained using the values obtained from the On/Off control graph.

If a Proportional Band of greater than 100% gives less oscillation and overshoot than the previous settings, leave the PID values as they are. Otherwise, return the setting for P to the previous value.

Proportional control sets the band within which the controller will vary time the heater spends on and off. Outside this band the heater will be always on or always off. If a slow response is observed, or large oscillations occur in temperature, reduce the value of P. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Integral control can be adjusted to reduce offset in the temperature. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of I to the previous value.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme, reduce the value of D. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the temperature over time as it rises from a low value. Compare this to the initial graph.

If time permits, create a new results sheet and repeat the optimisation process with the gear pump set to a speed of 50% to circulate (stir or mix) the water in the process vessel. Return the gear pump setting to 0%.

Effect of Process Lag

Process lag may be investigated using the holding tube provided with the PCT40. Disconnect the tube from the outlet of the coil (labelled T3), and instead connect the large diameter holding tube. Connect the other end to the temperature sensor T4, mounted at the back of the plinth to the left of the large process vessel. Connect the outlet of this fitting to the tube removed from the coil and direct the other end to drain.

The process variable monitored by the PID controller will now be the temperature at the end of the holding tube, T4, although the temperature at the end of the coil, T3, is also logged. To change the process variable in the software, select the PID control box (labelled 'Control') on the mimic diagram screed. From the process variable drop-down box, select T4. Leave the control variable as 'Heater' and the control action as 'Reverse'. The PID values may be left at their optimised values from the previous section of the exercise.

Repeat the investigations of disturbances and set point change, now monitoring T4 instead of T3. Note any difference in initial speed of response and the time within which the system settles. If time allows, the PID optimisation process may be repeated with the holding tube in place, to investigate any difference in optimum values due to process lag.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. 'Flow Rate', 'Integral Setting', etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise Y).

Each set of data not already graphed as part of the procedure should be plotted on a graph of temperature T3 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level control exercises have already been performed, compare the ease of optimisation for temperature control with the optimisations for PID level control. Compare the results obtained using PID temperature control against those using a simple on/off controller (as in Exercise W) and time proportioning control (Exercise X). Discuss the suitability of PID control for regulating process temperature.

Exercise Z: Manual control of pump speed

Objective

To manually control the temperature of the water exiting a coil inside a heated water bath within a process vessel, by controlling the rate of flow through the coil or the temperature of the water bath.

Overview

The temperatures within the process vessel and coil are monitored using thermocouple type sensors. A continuous flow of water is passed through the coil within the vessel using a gear pump. The water within the vessel is heated by a heating element, and heat is transferred to the water within the coil. By manually controlling the speed of the pump or the temperature of the water bath, the speed of flow through the coil is controlled. The effect of adding a holding tube is also investigated.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the valve SOL 1 to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 8: Temperature Control (indirect heating)’.

In the software, switch on SOL 1 using the switch on the software display and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then switch off SOL 1.

Disconnect the tube from the small process vessel and SOL 1.

Take the long length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to drain. Fully open the drain valve.

Take a length of tubing with a quick release fitting at both ends. Connect SOL 1 to the right hand connection on the gear pump.

Take a length of tubing with a quick release fitting on one end and a Guest push fitting on the other. Connect the other gear pump connection to the coil.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Select ‘Configure...’ from the Sample menu. Set data logging to Automatic at 30 second intervals with Continuous duration.

Check that the temperature readings T1, T2 and T3 are giving sensible values (usually between 5 and 30 degrees Celsius depending on mains water temperature).

Process fluid flow rate

The temperature of fluid exiting the vessel is controlled by controlling the flow rate of the fluid through a coil, which is immersed in a heated water bath, and hence the time available for heat transfer between the water bath and the process fluid.

The heater may be controlled using time proportional control to maintain a constant bath temperature.

Select the Heater Control button beneath the small process vessel on the software screen.

Check that the Proportional Band, Integral Time and Derivative Time are all set to 0.

Set a Set Point value of 30 °C and a cycle time of 60 seconds. If the mains water temperature is close to 30 °C then a higher Set Point should be chosen- at least 10 degrees higher than mains water temperature is recommended.

Set the Mode of Operation to Automatic control. The controller is now configured as a time proportional controller.

Apply and close the window.

Open valve SOL 1 by clicking on the SOL 1 switch in the software.

Select the Pump Control button situated above the Pump spin box on the software screen.

Set the controller to Manual control, and in the Manual Output box set a constant flow rate for water through the coil of 30%.

Apply the settings but do not close the controller window.

Allow time for the water bath in the process vessel to come up to temperature and stabilise (temperature T1).

Select the  icon to begin data logging.

Using the Manual Output setting, adjust the flow rate to reach and maintain an exit temperature T3 of 30 °C (choose a higher value if the mains water temperature is close to 30 °C).

Continue logging for 5 minutes while controlling the flow rate, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Disturbances

It is possible to introduce a disturbance to the system coil by changing the temperature of the water bath:

Select the icon to begin data logging.

In the software, select the Heater Control and change the Set Point value to 50 °C. Select Apply and close the controller window.

Open the Pump Control again.

Maintain the temperature at the exit of the coil at 30 °C (or the chosen Set Point) as the water in the process vessel heats. Note the control actions required to maintain the temperature.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Water bath temperature

The exit temperature of the process fluid may be controlled by controlling the temperature of the heated bath through which the process fluid passes.

Set the Manual Output for the pump speed to 30%, and close the controller window. This will now maintain a constant fluid flow rate through the coil.

Select the Heater Control button beneath the small process vessel on the software screen.

Set the Mode of Operation to Manual Control.

The heater may be controlled by setting the Manual Output to 0% (Off) and 100% (On).

Select the icon to begin data logging.

By controlling the heater manually, maintain the exit temperature T3 of the process fluid at 30 °C.

Continue controlling the heater manually to maintain the T3 Set Point temperature for five minutes, then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Record any differences between the time required for the water to rise or fall in temperature. Note any time lag between applying a control action and observing its effect.

Disturbances

It is possible to introduce a disturbance by changing the flow rate through the coil:

Select the icon to begin data logging.

In the software, select the Pump Control and change the Set Point value to 100%. Select Apply and close the controller window.

Open the Heater Control again.

Maintain the temperature at the exit of the coil at 30 °C (or the chosen Set Point) as the increased process fluid flow rate. Note the control actions required to maintain the temperature.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Holding Tube

The system may be modified by the addition of a holding tube after the process fluid exits the coil. A suitable tube has been provided with the PCT40 base unit.

In the Pump Control, set the Mode of Operation to Manual and the Manual Output to 0%.

In the Heater Control, set the Mode of Operation to Manual and the Manual Output to 0%.

Disconnect the flexible drain tube from the exit to the coil, and connect the holding tube. Connect the other end of the holding tube to the fitting for temperature sensor T4, situated behind the large process vessel.

Repeat the investigations of process fluid flow rate and water bath temperature described earlier in this exercise, but this time controlling the exit temperature for the holding tube, T4. The pump controller should be reset to use T4 as the process variable instead of T3 (select T3 from the drop-down selection box). Remember to create a new results sheet for each set of results.

If laboratory time permits then the investigations of disturbances may also be repeated.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. 'Disturbances', etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise Z).

Each set of data should be plotted on a graph of temperature T3 against time (without the holding tube) or T4 against time (with the holding tube).

Write up your experiment, commenting on the heating and cooling characteristics of a continuous indirect heating process and the actions required for manual control of the process. Give examples of situations in which indirect heating would be more suitable than direct heating, and contrast the characteristics of this heating method with those of direct heating. Comment on the sensitivity of the process to disturbances such as that investigated.

Exercise AA: Proportional temperature input with PID control

Objective

To control the temperature of water exiting a coil passing through a heated water bath in a process vessel, with PID control of a gear pump driving flow into the coil and time proportional control of the bath temperature.

Overview

The temperatures within the process vessel and coil are monitored using thermocouple type sensors. Process fluid is passed through the coil within the vessel using a gear pump, which is controlled by a PID controller that monitors the temperature of the process fluid leaving the coil. The water within the vessel is heated by a heating element, and heat is transferred to the water within the coil. The water is heated by a heating element which is controlled by a time proportional controller that monitors the temperature of the water bath within the process vessel.

Equipment Required

PCT40 bench with small process vessel containing a heating coil.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. The lid with heating coil should be in position on the small process vessel, with the coil surrounding the heating element. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable supplied.

Fill the small process vessel with water:

Using a length of tubing with a quick release fitting at both ends, connect the solenoid valve SOL 1 to one of the fittings on the side of the small process vessel. Ensure that the other fitting on the side of the process vessel is not connected.

Close the drain valve on the process vessel.

Run the PCT40 software and select ‘Section 8: Temperature Control (indirect heating)’.

In the software, switch on the valve SOL 1 using the switch on the software screen and watch as the small process vessel fills with water.

Wait until the coil inside the vessel is fully covered with water, then switch off SOL 1.

Disconnect the tube from the small process vessel and SOL 1.

Take the long length of tube with a quick-release fitting at one end and a drain valve at the other. Connect this end to the other side of the coil, and direct the opposite end of the tube to drain. Fully open the drain valve.

Take a length of tubing with a quick release fitting at both ends. Connect SOL 1 to the right hand connection on the gear pump.

Take a length of tubing with a quick release fitting on one end and a Guest push fitting on the other. Connect the other gear pump connection to the coil.

Procedure

SAFETY NOTE: During this exercise the apparatus may reach temperatures hot enough to cause burns or scalds. Do not touch the process vessel during the exercise, or remove the coil or sensors from within the vessel. Allow the apparatus to cool before draining the water or disconnecting any of the tubes from the process vessel.

Select 'Configure...' from the Sample menu. Set data logging to Automatic at 30 second intervals with Continuous duration.

Open valve SOL 1.

In the software, select the Pump Control button for the gear pump controller. Enter a Set Point value for the temperature of 30 degrees centigrade for water exiting the coil (measured by T3). If the temperature of the local mains water supply is close to 30 °C then a higher set point value may be used instead. A value of at least 10 °C higher than the mains water temperature is recommended.

Set the PID values for the controller. Suggested values are 100% for Proportional Band, 0s for Integral Time Constant and 0s for Derivative Time Constant.

Set the Mode of Operation to Automatic. Apply the setting and close the controller window. The gear pump should begin to operate.

Select the Heater Control button situated beneath the small process vessel on the software screen.

Enter a Set Point value for the temperature of 50 degrees centigrade for water exiting the coil (measured by T3). A value of at least 20 °C higher than the process fluid temperature Set Point (T3, set in the pump controller) is recommended, so the Set Point should be modified if the local mains water temperature is close to 30 °C.

Set the values for the controller in the appropriate boxes in the software. Set the Proportional Band to 0%, Integral Time Constant to 0s and Differential Time Constant to 0s. This configures the controller as an On/Off controller with a fixed hysteresis of 0.5% of full range.

Set a Cycle Time of 60 seconds, and Mode of Operation to Automatic. The controller is now configured for Time Proportional Control of the heater.

Select the GO icon to begin data logging.

Log the sensor outputs as the temperature in the process vessel reaches the Set Point and stabilises. Continue logging for a further 5 minutes (or until the temperature T3 stabilises), then select the STOP icon to stop logging.

In the software, select the icon to create a new results sheet.

Temperature Set Point for Water Bath

Investigate the effect of changing the set point temperature of the heater controller:

Create a new results sheet by selecting the icon.

In the software, click on the heater controller and alter the temperature set point to 60 °C (unless the initial set point value chosen was not 50 °C, when a value of 10 °C higher than the initial set point is suggested instead). Apply the new setting and close the controller window.

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

In the software, click on the heater controller and alter the temperature set point to 70 °C. Apply the new setting and close the controller window.

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Note that the heater circuit includes a safety cut-out which shuts off power to the heater if the temperature in the vessel exceeds approximately 80 °C. Set point values should therefore be kept well below this temperature.

Leave the Set Point at 70 °C for the next part of the exercise.

Temperature Set Point for Flow Rate Controller

Investigate the effect of changing the set point temperature for the gear pump controller:

In the software, click on the Pump Controller and alter the temperature set point to 35 °C (unless the initial set point value chosen was not 30 °C, when a value of 5 °C higher than the initial set point is suggested instead). Apply the new setting and close the controller window.

Select the icon to begin data logging.

Log the temperature for 10 minutes, and then select the icon to finish data logging.

Create a new results sheet by selecting the icon.

Repeat the procedure, altering the set point and recording the change in temperature over time. Suggested values for the temperature set point value are 40 and 45 °C, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data. Note that during indirect heating it is unlikely that process fluid temperatures of greater than 50 °C will be achievable.

Return the Set Point for the pump controller to its original value (usually 50 °C).

Return the Set Point for the heater controller to its original value (usually 30 °C).

PID Settings and optimisation

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Begin with the process vessel set up as described at the start of this laboratory sheet. If the apparatus has been used recently before this section of the exercise it will be necessary to cool the water in the process vessel before beginning this section. This may be speeded up by increasing the flow rate through the coil and turning off the heater:

Select the Heater Controller. Set Mode of Operation to Manual and Manual Output to 0%. Apply and close the window.

Select the Pump Controller and set Mode of Operation to Manual. Set the Manual Output to 100% to allow full flow through the coil. When the temperature of the process fluid (T1, monitored on the main display screen) has cooled to around 30 °C, set the Manual Output to 0%. Apply and close the window.

Select the Heater Controller. Set Mode of Operation to Automatic. The Set Point should be 50 °C (or the original Set Point setting if this was higher). Apply and close the window.

Set the controller to provide On/Off control (set P to 0%, and check that I, D and Cycle Time are all set to 0s).

Set the temperature Set Point to 40 °C (this allows room for overshoot during the initial tuning process).

Set the controller to Automatic Control, Apply the new settings and close the controller window.

Select the GO icon to begin data logging.

Wait as the temperature rises to the set point and overshoots. Continue logging as the controller starts the gear pump, increasing the flow rate and reducing the water temperature. Continue logging until the controller switches off the pump and the temperature begins to rise once more, then select the STOP icon to finish data logging.

Plot a graph of time against water temperature at the coil outlet, T3.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

$I = t$

$D = t / 6$

Set these values in the software.

Change the temperature set point to 0 °C, and cool the water in the vessel to 30 °C or less. At this point it is possible to temporarily increase the flow rate through the coil to accelerate the cooling process. Return the flow rate to its previous value before continuing with the exercise.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the  icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 15 minutes is suggested.

Select the  icon to finish data logging.

From these new results, plot a graph of temperature T3 against time and observe the shape of the graph.

If the figure for Proportional Band obtained by this method is very small (less than 5%), and the Integral Time very large (more than 30s) then the method chosen for finding approximate tuning values may not be suitable and the best value for Proportional Band may be greater than 100%.

Set the Proportional Band to 200%, the Integral Time to 60s and the Derivative Time to 0s.

Create a new results sheet by selecting the  icon in the tool bar of the software.

Return the temperature set point to 40 °C

Select the  icon to begin data logging.

Log the temperature as it rises and then settles around the set point value. Logging should continue until any oscillations have settled- 10 minutes is suggested.

Select the  icon to finish data logging.

Plot a graph of temperature against time and compare the shape of the graph to that obtained using the values obtained from the On/Off control graph.

If a Proportional Band of greater than 100% gives less oscillation and overshoot than the previous settings, leave the PID values as they are. Otherwise, return the value of P to the basic value obtained from the initial measurements.

Proportional control sets the band within which the controller will vary time the heater spends on and off. Outside this band the heater will be always on or always off. If a slow response is observed, or large oscillations occur in temperature, reduce the value of P. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Integral control can be adjusted to reduce offset in the temperature. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme, reduce the value of D. Investigate the results of the changed value by plotting a graph of the temperature as it rises from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the temperature over time as it rises from a low value. Compare this to the initial graph.

Holding Tube

The system may be modified by the addition of a holding tube after the process fluid exits the coil. A suitable tube has been provided with the PCT40 base unit.

In the Pump Control, set the Mode of Operation to Manual and the Manual Output to 0%.

In the Heater Control, set the Mode of Operation to Manual and the Manual Output to 0%.

Disconnect the flexible drain tube from the exit to the coil, and connect the holding tube. Connect the other end of the holding tube to the fitting for temperature sensor T4, situated behind the large process vessel.

Repeat the investigations of process fluid flow rate and water bath temperature described earlier in this exercise, but this time controlling the exit temperature for the holding tube, T4. The pump controller should be reset to use T4 as the process variable instead of T3 (select T3 from the drop-down selection box). Remember to create a new results sheet for each set of results.

If laboratory time permits then the investigations of disturbances may also be repeated.

When you have finished, set the gear pump to 0% and the heater power to 0%. Switch off SOL 1.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘T1 Set Point’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise AA).

Each set of data not already graphed as part of the procedure should be plotted on a graph of temperature T3 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level control exercises have already been performed, compare the ease of optimisation for temperature control with the optimisation for PID level control. Discuss the suitability of PID control for regulating process temperature.

Exercise BB: Manual control of flow rate

Objective

To manually control flow rate by varying the speed of a peristaltic pump.

Overview

Flow through a flow sensor is produced using a peristaltic pump. By manually controlling the speed of the pump, the speed of flow is controlled.

Equipment Required

PCT40 bench.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Check that the mains water supply to the apparatus is off and the pressure regulator is set to minimum. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable provided.

Take a length of 6.3mm diameter peristaltic tubing with a self-sealing fitting at one end. Connect the quick-release fitting to the socket on SOL 1. Pass the other end from right to left through the left-hand peristaltic pump (pump A) to a suitable drain. Leave the lid of the pump open at this stage.

Take a second length of tube with a grey Guest push fitting at one end. Remove the quick-release sealing plug from the end of the inlet plumbing (in front of SOL 1). Connect the tubing to the pipe where the plug was located. Pass the other end from right to left through the right-hand peristaltic pump (pump B) to a suitable drain. Leave the lid of the pump open at this stage.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

Run the PCT40 software and select ‘Section 9: Flow Control’.

In the software, set the speed of pump B to 50%. Check that the rotor within the pump rotates.

Turn the mains water supply to the apparatus on.

Carefully close the lid of the pump, ensuring that the tubing passes between the guides on the sides of the pump and is not pinched. Water should be drawn through the pump.

Increase the pump speed to 100%.

Adjust the pressure regulator on the inlet pipe of the apparatus to set the maximum flow rate:

Pull the large grey knob on the pressure regulator away from the body of the regulator.

Gradually turn the knob to adjust the pressure regulator setting until the flow rate F1 is approximately 1400ml/min. Clockwise rotation opens the valve (increases flow), anticlockwise rotation closes the valve (decreases flow).

Depending on variations in the local water pressure, the flow rate figure may oscillate.

If local water pressure is low then a lower value than 1400ml/min may be set. Where this is the case, always set a value slightly lower than the maximum flow rate to protect against spikes in pressure.

Push the knob back in to fix the setting.

NOTE: If the flow rate exceeds 1500ml/min then the flow meter may give a reading of 0ml/min. The flow meter is not designed to read flow rate values of greater than 1500ml/min. The regulator valve must be closed to reduce the flow below this value.

Carefully close the lid of the peristaltic pump, ensuring that the tubing is not pinched by the lid, and check that water is now drawn through the tubing and out to drain.

Reduce the speed of pump B to 0%.

Select 'Configure...' from the Sample menu. Set data logging to Automatic at 5 second intervals with Continuous duration.

Prime pump A:

In the software, open valve SOL 1

Set the speed of pump A to 50%

When the pump operates, carefully close the lid of the pump, ensuring that the tubing is not pinched by the lid.

Check that water is now drawn through the pump to drain.

Set the speed of pump A to 0%

Manual control of flow rate

Check that the valve SOL 1 is open (on).

In the software, set the speed of pump A to 50%.

Select the  icon to begin data logging.

Monitoring the flow rate F1, adjust the speed of pump A to give a flow rate of 700ml/min, using the up and down arrows.

If the signal oscillates too much (there is too much noise) to be able to easily control the flow rate, it may be necessary to use filtering in order to average out the signal. Filtering can be set in the Options menu under 'IFD Sampling Parameters'. Depending on local conditions, Linear or Constant filtering is probably the most appropriate, but if this delays the response too much then Exponential may be a better choice.

Note how easy it is to maintain a fixed flow rate using manual control, and how quickly the system responds to control actions.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Disturbances

Within the software, it is possible to introduce a disturbance to the system by increasing the flow rate using a second peristaltic pump:

Select the icon to begin data logging.

In the software, set the speed of pump B to 10%

Note how rapidly the flow rate changes as a result of this new setting, and the control actions required to return the flow rate to its previous value.

Set the speed of pump B to 30%, and once more note the speed of response and the action required to return the flow rate to the Set Point.

Set pump B to 0%. Note any difference between the response produced by an increase in pump speed.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Disturbance’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise BB).

Each set of data not already graphed as part of the procedure should be plotted on a graph of flow rate F1 against time.

Write up your experiment, discussing the speed of response when controlling Flow Rate directly, and the ease of manual control for this variable. Comment on the sensitivity of the process to disturbances.

Exercise CC: Proportional flow rate input with PID control

Objective

To control the flow rate of water using PID control of a peristaltic pump, using a flow sensor to monitor the rate.

Overview

Flow is directed through a flow sensor by a peristaltic pump. The flow sensor sends a signal to the computer that is proportional to the flow rate. The PID controller within the software monitors this signal and adjusts the speed of the pump to reach and maintain the required flow rate.

Equipment Required

PCT40 bench.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Check that the mains water supply to the apparatus is off and the pressure regulator is set to minimum. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable provided.

Take a length of 6.3mm diameter peristaltic tubing with a self-sealing fitting at one end. Connect the quick-release fitting to the socket on SOL 1. Pass the other end from right to left through the left-hand peristaltic pump (pump A) to a suitable drain. Leave the lid of the pump open at this stage.

Take a second length of tube with a grey Guest push fitting at one end. Remove the quick-release sealing plug from the end of the inlet plumbing (in front of SOL 1). Connect the tubing to the pipe where the plug was located. Pass the other end from right to left through the right-hand peristaltic pump (pump B) to a suitable drain. Leave the lid of the pump open at this stage.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

Procedure

NOTE: Peristaltic pumps typically do not begin to operate until the input reaches approximately 30%. During PID control, if the Proportional Band is loo large then the controller will not send a great enough input value to begin pump operation. If the pump fails to operate under PID control, try reducing the PB value.

Switch on the mains water supply to the apparatus.

Run the PCT40 software and select ‘Section 9: Flow Control’.

Select ‘Configure...’ from the Sample menu. Set data logging to Automatic at 5 second intervals with Continuous duration.

Prime the pumps:

In the software, open valve SOL 1

Set the speed of pump B to 50%

When the pump operates, carefully close the lid of the pump, ensuring that the tubing is not pinched by the lid.

Check that water is now drawn through the pump to drain

Set the speed of pump B to 0%

Click on the PID controller for pump A

Select the Manual Control radio button in the top right section of the PID control window

In the bottom right section, set the pump speed to 50%

When the pump operates, carefully close the lid of the pump, ensuring that the tubing is not pinched by the lid.

Check that water is now drawn through the pump to drain

Set the speed of pump A to 0%

Set the PID values for the controller in the appropriate boxes in the software. Suggested starting values are a Set Point of 700ml/min, Proportional Band (P) of 5%, Integral Time Constant (I) of 0s and Differential Time Constant (D) of 0s.

In the Sample/Configure… menu, set the software to log at intervals of 1 second.

If the signal oscillates too much (there is too much noise) to be able to easily control the flow rate, it may be necessary to use filtering in order to average out the signal. Filtering can be set in the Options menu under ‘IFD Sampling Parameters’. Depending on local conditions, Linear or Constant filtering is probably the most appropriate, but if this delays the response too much then Exponential may be a better choice.

Select the GO icon to begin data logging.

Log the flow rate until it settles to within a narrow range of the set point, then select the STOP icon to stop logging.

Disturbances

Within the software, it is possible to introduce a disturbance to the flow rate by altering the speed of pump B:

In the software, select the icon to create a new results sheet.

Select the GO icon to begin data logging.

In the software, change the speed of pump B to 10%.

Log the flow rate as the PID controller adjusts to the changed flow rate through the orifice. Wait until the flow rate settles to a steady value.

Change the speed of pump B to 20%. Wait until the flow rate settles to a steady value.

Change the speed of pump B to 0%. Wait until the flow rate settles to a steady value, and then select the icon to finish data logging.

Flow Rate Set Point

Investigate the effect of changing the set point flow rate:

Create a new results sheet by selecting the icon.

In the software, alter the flow rate set point to 1000ml/min.

Select the icon to begin data logging.

Log the flow rate until it settles at the new set point, and then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in flow rate over time. Suggested values for the flow rate set point are 500ml/min and 300ml/min, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data.

Return the flow rate set point to its original value.

PID Settings and optimisation

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Create a new results sheet by selecting the icon in the tool bar of the software.

Set the software to provide On/Off control (set P to 0%).

Set the flow rate set point to 1000ml/min (this allows for overshoot during the initial tuning process).

Select the icon to begin data logging.

Wait as the flow rate rises to the set point and overshoots. Continue logging as the controller starts the peristaltic pump, introducing flow through the second pump and therefore reducing flow through the first pump as the pressure regulator maintains constant water pressure. Continue logging until the controller switches off the pump and the flow rate begins to rise once more, then select the icon to finish data logging.

Plot a graph of flow rate against time.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

$P = y / 3$

I = t

D = t / 6

Set these values in the software.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Log the flow rate as it rises and then settles around the set point value. Logging should continue until any oscillations have settled.

Select the icon to finish data logging.

From these new results, plot a graph of flow rate against time and observe the shape of the graph.

Proportional control sets the gain of the controller. If a slow response is observed, or large oscillations occur in flow, reduce the value of P. Investigate the results of the changed value by plotting a graph of the flow as it rises from a low value and comparing this to the initial results.

Integral control can be adjusted to reduce offset in the flow rate. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the flow rate as it rises from a low value and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme, reduce the value of D. Investigate the results of the changed value by plotting a graph of the flow rate as it rises from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the flow rate over time as it rises from a low value. Compare this to the initial graph.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Flow Rate’, ‘Integral Setting’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise CC).

Each set of data not already graphed as part of the procedure should be plotted on a graph of flow rate F1 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level and temperature control exercises have already been performed, compare the ease of optimisation for flow control with the optimisations for PID level and temperature control. Discuss the suitability of PID control for regulating flow rate.

Exercise DD: Manual control of proportioning valve setting

Objective

To manually control static line pressure by varying the setting of a proportioning solenoid valve.

Overview

Flow is directed through an orifice with the flow rate controlled using a proportioning solenoid valve. This produces a pressure drop across the orifice, which is monitored using a differential pressure sensor. By manually controlling the setting of the valve, this static line pressure is controlled.

Equipment Required

PCT40 bench.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Check that the mains water supply to the apparatus is off and the pressure regulator is set to minimum. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable provided.

Take a length of tube with a quick release fitting at both ends. Connect one end to the socket on the PSV. Connect the other end to one of the sockets in the side wall of the small process vessel.

Take a second length of tube with a quick-release fitting at both ends. Connect one end from the outlet (left hand socket) of the gear pump to the right hand (P3) socket on the manifold block.

Take a length of tubing with a Guest push fitting at one end and an open end at the other. Connect the tubing to the right-hand connection at the back of the manifold block, and direct the other end to drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

To enable the gear pump to operate, the water level in the small process vessel must be above the level sensor in the vessel. To fill the small process vessel with water, it is possible to remove the lid and fill from the top. Care must be taken not to damage the attachments on the lid. The preferred procedure for filling the vessel is as follows:

Close the drain valve at the base of the small process vessel.

Run the PCT40 software and select ‘Section 10: Pressure Control’.

In the software, set the PSV 0% and fully close the pressure regulator valve (Pull the large grey knob on the pressure regulator away from the body of the regulator, and turn the grey knob fully anticlockwise).

Turn on the mains water supply to the apparatus.

Set the PSV valve to 50% and slowly open the pressure regulator valve to achieve a flow rate of 750 l/min.

Watch as water flows into the small process vessel. Once the fluid level reaches the level sensor probe, set the PSV valve to 0%.

Detach the tube from the small process vessel and connect it to the gear pump inlet (right hand socket).

Procedure

Click on the ‘PID’ button beside the PSV valve on the software screen.

Select the Manual Control radio button in the top right section of the PID control window

In the bottom right section, set the pump speed to 50%. Close the PID control window.

On the software screen, set the gear pump to 50%.

Adjust the pressure regulator on the inlet pipe of the apparatus to set the median flow rate:

Gradually turn the grey knob to adjust the pressure regulator setting until the flow rate F1 is approximately 750 l/min. Clockwise rotation opens the valve (increases flow), anticlockwise rotation closes the valve (decreases flow).

Depending on variations in the local water pressure, the flow rate figure may oscillate.

Push the knob back in to fix the setting.

Check that water is flowing through the manifold black and out to drain.

Select ‘Configure...’ from the Sample menu. Set data logging to Automatic at 5 second intervals with Continuous duration.

Manual control of static line pressure

Select the icon to begin data logging.

Click on the ‘PID’ button beside the PSV valve on the software screen.

Check that the Manual Control radio button in the top right section of the PID control window is selected.

Monitoring the differential pressure P3, adjust the setting of the PSV in the bottom right hand section of the PID control window, to give a flow rate of 700ml/min. Note the pressure differential across the orifice at this flow rate (this is likely to be in the region of 150mm to 200mm). Pick a set point value close to this pressure differential (e.g. 150mm or 200mm), and attempt to reach and maintain this set point by controlling the setting of the PSV.

If the signal oscillates too much (there is too much noise) to be able to easily monitor the pressure differential, it may be necessary to use filtering in order to average out the signal. Filtering can be set in the Options menu under ‘IFD Sampling Parameters’. Depending on local conditions, Linear or Constant filtering is probably the most appropriate, but if this delays the response too much then Exponential may be a better choice.

Note how easy it is to maintain a constant pressure using manual control, and how quickly the system responds to control actions.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Disturbances

Within the software, it is possible to introduce a disturbance to the system by changing the speed of the gear pump that is connected in series with the PSV and the manifold block orifice:

Select the icon to begin data logging.

In the software, set the speed of the gear pump to 70%.

Note how rapidly the pressure changes as a result of this new setting, and the control actions required to return the pressure to its previous value.

Set the speed of the gear pump to 30%, and once more note the speed of response and the action required to return the pressure to the Set Point.

Set the gear pump to 50%. Repeat the previous observations.

Select the icon to finish data logging.

Create a new results sheet by selecting the icon in the tool bar of the software.

Note that the differential pressure sensor is not designed for use at inlet flow rates of greater than 1500ml/min. The combined settings for the PSV and the gear pump should therefore be kept low enough that the flow rate remains below this value.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. 'Disturbances', etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise DD).

Each set of data should be plotted on a graph of pressure P3 against time.

Write up your experiment, discussing the speed of response when controlling line pressure directly, and the ease of manual control for this variable. Comment on the sensitivity of the process to disturbances.

Exercise EE: Proportional pressure input with PID control

Objective

To control the pressure drop across an orifice using PID control of a proportioning solenoid valve.

Overview

Flow is directed through an orifice with the flow rate controlled using a proportioning solenoid valve. This produces a pressure drop across the orifice, which is monitored using a differential pressure sensor. The pressure sensor sends a signal to the computer that is proportional to the differential pressure across the orifice, which is in turn affected by the flow rate. The PID controller within the software monitors the pressure signal and adjusts the PSV valve setting to reach and maintain the required pressure across the orifice.

Equipment Required

PCT40 bench.

Equipment set up

Ensure that the apparatus has been set up according to the Installation section. Check that the mains water supply to the apparatus is off and the pressure regulator is set to minimum. The apparatus should be connected to a suitable PC with the PCT40 software installed, using the grey USB cable provided.

Take a length of tube with a quick release fitting at both ends. Connect one end to the socket on the PSV. Connect the other end to one of the sockets in the side wall of the small process vessel.

Take a second length of tube with a quick-release fitting at both ends. Connect one end from the outlet (left hand socket) of the gear pump to the right hand (P3) socket on the manifold block.

Take a length of tubing with a Guest push fitting at one end and an open end at the other. Connect the tubing to the right-hand connection at the back of the manifold block, and direct the other end to drain.

Check that the drain valve on the end of the plinth is open and that it is connected to a suitable drain.

To enable the gear pump to operate, the water level in the small process vessel must be above the level sensor in the vessel. To fill the small process vessel with water, it is possible to remove the lid and fill from the top. Care must be taken not to damage the attachments on the lid. The preferred procedure for filling the vessel is as follows:

Close the drain valve at the base of the small process vessel.

Run the PCT40 software and select ‘Section 10: Pressure Control’.

In the software, set the PSV 0% and fully close the pressure regulator valve (Pull the large grey knob on the pressure regulator away from the body of the regulator, and turn the grey knob fully anticlockwise).

Turn on the mains water supply to the apparatus.

Set the PSV valve to 50% and slowly open the pressure regulator valve to achieve a flow rate of 750 l/min.

Watch as water flows into the small process vessel. Once the fluid level reaches the level sensor probe, set the PSV valve to 0%.

Detach the tube from the small process vessel and connect it to the gear pump inlet (right hand socket).

Procedure

Click on the ‘PID’ button beside the PSV valve on the software screen.

Select the Manual Control radio button in the top right section of the PID control window

In the bottom right section, set the pump speed to 50%. Close the PID control window.

On the software screen, set the gear pump to 50%.

Adjust the pressure regulator on the inlet pipe of the apparatus to set the median flow rate:

Gradually turn the grey knob to adjust the pressure regulator setting until the flow rate F1 is approximately 750 l/min. Clockwise rotation opens the valve (increases flow), anticlockwise rotation closes the valve (decreases flow).

Depending on variations in the local water pressure, the flow rate figure may oscillate.

Push the knob back in to fix the setting.

Check that water is flowing through the manifold black and out to drain.

Select ‘Configure...’ from the Sample menu. Set data logging to Automatic at 1 second intervals with Continuous duration.

Set the PID values for the controller in the PID controller window. Suggested starting values are a Set Point of 200mm, Proportional Band (P) of 50%, Integral Time Constant (I) of 10s and Differential Time Constant (D) of 0s.

If the signal oscillates too much (there is too much noise) to be able to easily control the flow rate, it may be necessary to use filtering in order to average out the signal. Filtering can be set in the Options menu under ‘IFD Sampling Parameters’. Depending on local conditions, Linear or Constant filtering is probably the most appropriate, but if this delays the response too much then Exponential may be a better choice.

Select the  icon to begin data logging.

Log the pressure differential P3 until it settles to within a narrow range of the set point, then select the  icon to stop logging.

Disturbances

Within the software, it is possible to introduce a disturbance to the flow rate, and therefore the differential pressure, by altering the speed of the gear pump:

In the software, select the icon to create a new results sheet.

Select the icon to begin data logging.

In the software, change the speed of the gear pump to 70%.

Log the pressure P3 as the PID controller adjusts to the changed flow rate through the orifice. Wait until the flow rate settles to a steady value.

Change the speed of pump B to 30%. Wait until the pressure P3 settles to a steady value.

Change the speed of pump B to 50%. Wait until the pressure P3 settles to a steady value, and then select the icon to finish data logging.

Differential Pressure Set Point

Investigate the effect of changing the set point flow rate:

Create a new results sheet by selecting the icon.

In the software, alter the set point to 150mm.

Select the icon to begin data logging.

Log the pressure P3 until it settles at the new set point, and then select the icon to finish data logging.

Repeat the procedure, altering the set point and recording the change in pressure over time. Suggested values for the set point are 100mm, 250mm and 300mm, but more values may be attempted if laboratory time allows. Remember to create a new results sheet for each set of data.

Return the set point to its original value.

PID Settings and optimisation

To begin tuning it is necessary to set initial values which can be modified to improve the control results obtained. Follow this simple procedure to find start point values from which to begin optimisation:

Create a new results sheet by selecting the icon in the tool bar of the software.

In the PID control window, set the software to provide On/Off control (set P to 0%).

Set the pressure set point to 150mm (this allows for overshoot during the initial tuning process).

Select Manual Control and set the PSV to 0%.

Select the icon to begin data logging.

Set the PSV to Automatic Control.

Wait as the pressure P3 rises to the set point and overshoots. Continue logging as the controller adjusts the PSV, increasing the flow rate and thus affecting the differential pressure across the orifice. Continue logging until the controller starts to close the PSV and the pressure begins to change once more, then select the icon to finish data logging.

Plot a graph of pressure P3 against time.

From the graph, determine the peak to peak variation, y, between the highest value of the overshoot and the lowest value of the undershoot.

Calculate the time between these two values, t.

From the values y and t, starting values may be found for P, I and D as follows

P = y / 3

I = t

D = t / 6

Set these values in the software.

Create a new results sheet by selecting the icon in the tool bar of the software.

Select the icon to begin data logging.

Log the pressure as it rises and then settles around the set point value. Logging should continue until any oscillations have settled.

Select the icon to finish data logging.

From these new results, plot a graph of pressure P3 against time and observe the shape of the graph.

Proportional control sets the gain of the controller. If a slow response is observed, or large oscillations occur in temperature, reduce the value of P. Investigate the results of the changed value by plotting a graph of the pressure as it rises from a low value and comparing this to the initial results.

Integral control can be adjusted to reduce offset in the pressure. If a significant offset is observed, reduce the value of I. Investigate the results of any change by plotting a graph of the pressure as it rises from a low value and comparing this to the initial results.

Return the value of I to the basic value obtained from the initial measurements.

Derivative control can be adjusted to reduce excessive oscillation. If oscillations are extreme, reduce the value of D. Investigate the results of the changed value by plotting a graph of the pressure differential as it increases from a low value and comparing this to the initial results.

From the graphs obtained, select values of P, I and D that give the best results. Perform a final test run, logging the pressure P3 over time as it rises from a low value. Compare this to the initial graph.

Results

For easy identification or results, it is suggested that each results sheet is renamed with a descriptive title (e.g. ‘Set Point’, ‘Integral Setting’, etc.). The entire workbook should be saved with a suitable filename for future reference (e.g. PCT40 Exercise EE).

Each set of data not already graphed as part of the procedure should be plotted on a graph of pressure P3 against time.

Make a comparison of each variation in the experimental conditions against the graph of the initial set of results, noting the difference in response. Comment on the results obtained by varying the values of P, I and D, and on the ease of optimisation of the process. If the level and temperature control exercises have already been performed, compare the ease of optimisation for pressure control with the optimisations for PID level and temperature control. Discuss the suitability of PID pressure control for regulating flow rate.