Chemical Engineering Department
University of Technology

Process Control Laboratory

Fourth Class
Laboratory Manual

Prepared by: Sana Wathiq
Nesma Balasim

Supervised by: Dr.Zaidoon Mohsin

Introduction

Process Control has often stood out in the chemical engineering curriculum as a necessary topic that is oddly disconnected from the rest of the curriculum. While control modeling still relies on conservation laws and other fundamentals of chemical engineering, its mathematical focus on process descriptions in the Laplace domain has made it appear to students as a course distinct from “regular” chemical engineering. In reality, process control is key to industrial practice and will draw upon an engineer’s theoretical knowledge and practical experience to be effective.

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Experiment No. (1)
Dynamic behavior of Stirred Tanks

Object:-

The object of the apparatus is to compare experimentally determined response of tank concentrations to a step change with those derived theoretically.

Introduction

Two constant volumes continuously operated stirred tanks are arranged in series and in each one is installed conductivity cell for measuring concentrations changes produced by deliberately in flow conditions. Provision is also made in the piping system (dead time).

Theory

Suppose that we have two stirred tank in series as shown in Fig.(l), each of them at constant volume, the stream input tank (1) with a flow rate (F) and concentration (C_1), then the stream exit to tank (2) with the same flow rate and concentration (C_2), this stream input the second tank with the same properties and exit from it with flow rate (F) and concentration C_3.

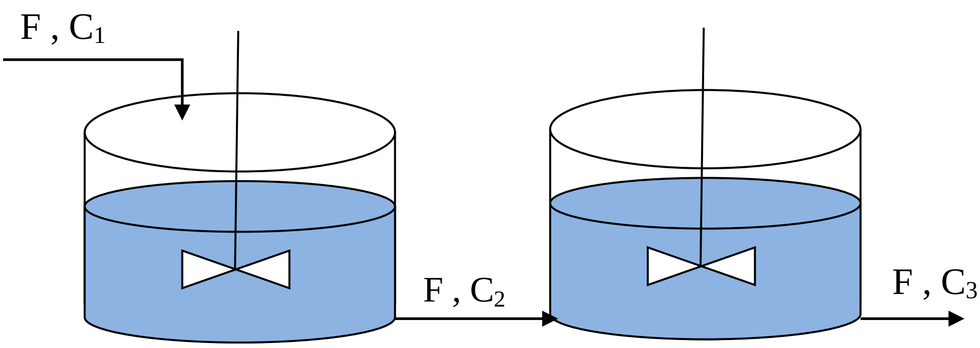


Fig.(l): Two stirred tank in series.

In both tanks, there is a conductivity cell for measuring the concentration changes.

By using mass balance, derive a mathematical model and predict the transfer function that describes the system.

Rate of mass input - Rate of mass output = Rate of accumulated

A mass balance on tank (1) gives:

$$F_1 C_1 - F_2 C_2 = \frac{V\, dC_2}{dt} \quad \text{.............} (1)$$

A mass balance on Lank (2) gives:

$$F_2 C_2 - F_3 C_3 = \frac{V\, dC_3}{dt} \quad \text{................} (2)$$

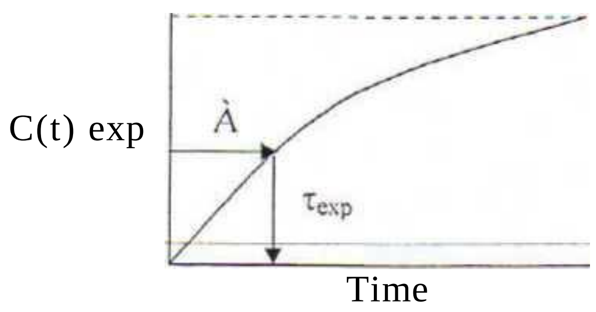
Procedure:-

1. Arrange the three way valve on the inlet to flow meter to be closed to the lines from both constant head tanks i.e. no feed to the first vessel.
2. Start both pumps and observe that liquid is pumped to the two constant head tanks vessels and returns to the feed tanks from the overflows.
3. Turn on the three way valve to allow the water in the first tank to pass into the first vessel at constant flow rate. The flow from the first vessel should flow through the other two vessels and to drain in order that a constant level can be obtained.
4. The conductivity readings of the two vessels are measured until reach steady state value.
5. Three way valves should be altered to allow NaCl solution to flow at the same rate of the water before.
6. Measure the conductivity changes at (1 minute) intervals after the change over from water to the NaCl solution (step response two stirred vessels in series).

Calculation

1. Change the results of conductivity to concentration by using calibration curve.
2. Derive the transfer function of the system.
3. Draw experimental result (C_1 - C_2) verses time for each tank.
4. Calculate x_{exp} for each tank.

A’ = A*0.63; A = Ultimate value



5. Calculate the time constant- theoretical for interacting system for each tank $\tau = \frac{V}{F}$

6. Calculate the time constant by using cald - well method:

Plot the functional response $\frac{Y}{A}$ versus time

Where:-

$$\frac{Y}{A} = \frac{(C_i - Cs)}{(Cf - Cs)}$$

And obtain t| at Y/A = 0.73

a. Apply $t_1 = 1.32\ (\tau_1 + \tau_2) \Leftrightarrow (\tau_1 + \tau_2) = \frac{t_1}{1.32}$

b. Calculate t_2 from: $t_2 = 0.5\ (\tau_1 + \tau_2)$

c. Use the value of t_2 in plotted Fig. in step to get (Y / A = P).

d. Use the value of P obtained in (standard figure) given and then get values (τ_1) and (τ_2) .

Discussion:-

Compare and discuss your experimental and theoretical results.

Experiment No.(2)
Stirred Tank Heater

Object

To study the dynamic response of two stirred tank heater in series.

Introduction

Steady state problems have been long known and studied in many fields such as fluid flow, hydraulics and heat transfer. In physical systems, the relationships for the changes of the variable with time can be derived from the same physical laws that used to predict steady state relationships in kinetic and equilibrium studies. The subjective of the dynamic analysis of the process is to see how variables change with time.

Many of the properties of the system and hence the process variable, will be function of time and the equation for the dynamic response of a particular variable with respect to changes in the input variables will be a differential equation.

Theory

Consider the two stirred tanks shown in Fig.(l) in which a liquid enters the tank (1) with a flow rate F (Cm^3/min) and a temperature T_i, (C°) which is healed by a coil (in which energy is transferred (Qi).

The temperature of the stream leaving the tank (1) is T_1 (C°), this stream enters tank (2).

It is desired to develop a mathematical model in which the temperature in the second tank is related to the input, variables **T_i,F,Q_i.** To find the transfer function of the system an energy balance should be made and then the unsteady state energy balance is:

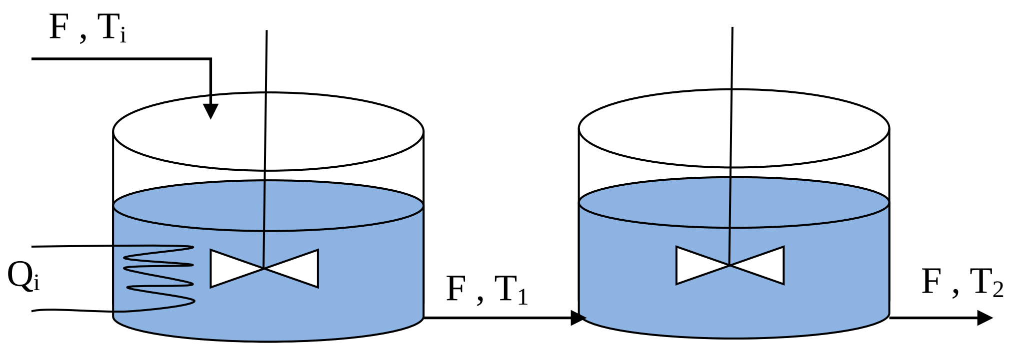


Fig. (1)

Rate of energy accumulated=Rate of energy input-Rate of energy output

Heat balance on tank (1):

$$F\rho\, Cp\, T_i + Q_i - F\rho Cp\, T_1 = V_1\,\rho\, Cp\,\frac{dT_1}{dt} \qquad \text{.............................. (1)}$$

Heat balance on tank (2):

$$F\,\rho\, Cp\, T_1 - F\,\rho\, Cp\, T_2 = V_2\,\rho\, Cp\,\frac{dT_2}{dt} \qquad \text{.............................. (2)}$$

Procedure

1. Let flow rate readings on scale 6.
2. From the output of the second tank you can get a stead state level in the two tanks.
3. Put on the heater and adjust the set point on 25 $C°$.
4. Record the steady state temperature of the two tanks.
5. Change the temperature from set point 25 $C°$ to 40 $C°$ (this means the disturbance is in the input energy). .
6. Record the temperatures in the two tanks every one minute until reach steady state conditions. It must be equal the reference temperature.

Calculation

1. Derive the transfer function of the system
2. Plot the response (output variable versus time) of the system for step disturbance in energy.
3. Calculate the theoretical time constants.
4. Plot the relation between temperature (T_1) and(T_2) verses time.
5. Calculate the transfer function ($\frac{T_{2(S)}}{Q_{(S)}}$) using Caldwell method.
6. Calculate the transfer function ($\frac{T_{2(S)}}{Q_{(S)}}$) using Process Reaction Curve (PRC) method.
7. Plot T_2 as function of time using the transfer functions obtained in step (5), (6) and the experimental results.

Discussion

1. Discuss the experimental results. •
2. Compare PRC method with Caldwell method, which one is the best?
3. Compare theoretical and experimental responses.
4. Suggest and discuss the type of controller used to control T_1 and T_2.

Experiment No. (3)
Dynamic behavior of Second Order Under-Damped System

Object:

Study the dynamic behavior of a second order under damped system by measuring the pressure drop in a U - tube manometer connected to an orifice meter.

Introduction:-

The measurement of steady state flow of single-phase fluid based on determination of pressure drop developed across flow construction through which the fluid is flowing.

The orifice plate, venture tube and dall flow tube are typical examples of sensors. The first is the more popular due to its simplicity and low cost. The last two are more expensive but also more accurate. Such sensor leads to a second order differential equation on applying force balance around them.

Theory:-

A second order system is one whose output, Y(t) is descried by the solution of a second order differential equation , as :-

$$\tau^2 \frac{d^2y}{dt^2} + 2\,\tau\,\varphi \frac{dy}{dt} + y = K_p\, X(t) \qquad \text{........... (1)}$$

Which lead to a transfer function of the form:-

$$\frac{Y(s)}{X\,(s)} = \frac{Kp}{\tau^2 s^2 + 2\,\tau\varphi s + 1} \qquad \text{................ (2)}$$

For A unit step change in the input X (s) = $\frac{A}{S}$, the solution depend on the damping factory **φ** .

If **φ** > 1 it is called over - damped.

If **φ** < 1 it is called under - damped.

If **φ** = 1 it is called critically - damped.

When the second order dynamics exhibit oscillation, it is the under damped, such systems are rather rare in chemical processes.

This equation leads with simple U - tube manometer connected through orifice meter as shown in figure (1):-

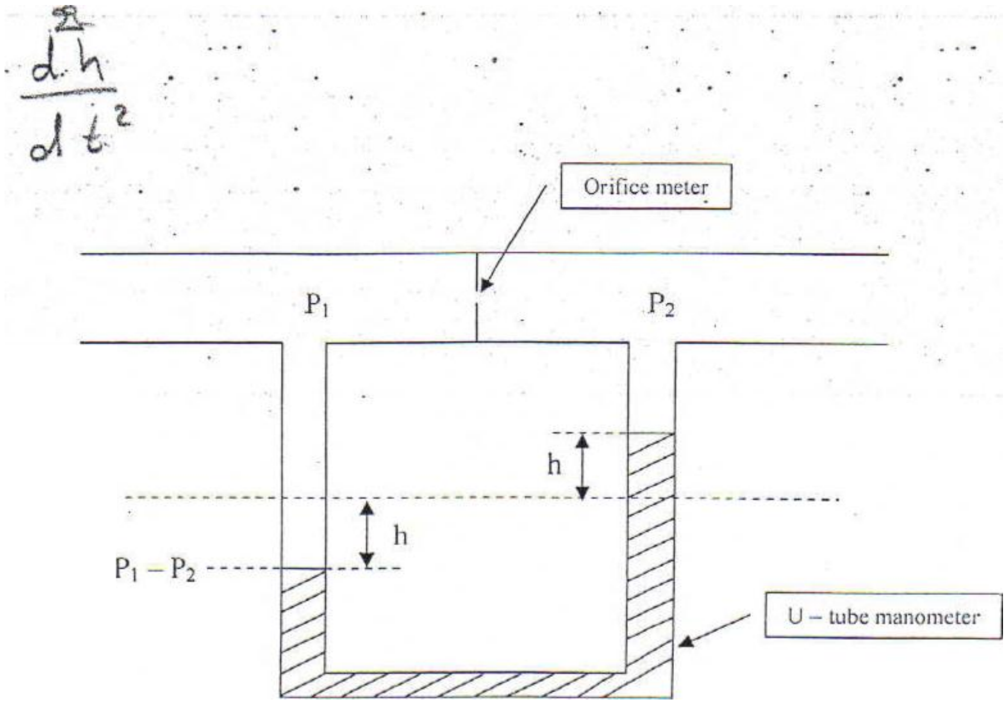


Figure (1) U - tube manometer

Applying Newton's Law:-

Balance of forces on the system = mass of system * acceleration [force due to pressure difference in the two legs (Pi - P_2)] - [force to liquid level difference in the two legs] - [force due to fluid friction] = mass of liquid in the tube * acceleration

$$\Delta P\, A - 2\,\rho\, g\, h\, A - \frac{32\,\mu\, L\, A}{d^2}\frac{dh}{dt} = A\, L\, \rho \frac{d^2h}{dt^2} \qquad \text{........ (3)}$$

Apply equation (3) , to figure (1) the following transfer function obtained :-

$$\frac{h(s)}{\Delta P(s)} = \frac{Kp}{\tau^2 s^2 + 2\,\tau\varphi s + 1} \qquad \text{................ (4)}$$

Where :-

$$\tau = \sqrt{\frac{L}{2g}} \quad , \mathbf{Kp} = \frac{gc}{2g\rho} \quad , \ \varphi = \frac{16\,\mu L}{g d^2 \rho}\sqrt{\frac{L}{2g}} \quad , \rho = \rho_{Hg} - \rho_{H_2O}$$

Procedure:-

1. Put the inlet fluid valve on position (1).
2. After reaching steady state in the mercury level, record the level change [Δh_{Hg} = 2h] and the volumetric flow rate for the valve setting.
3. Change the inlet valve to position (2) and repeat step (2) above. And repeat step (2) above. And then change the inlet valve to position (3) and
(4)....
4. From any steady state condition (position 1, 2, 3 or 4) of the process introduce a positive step change in the flow rate [e.g.:- change the valve

from position (2) to position (3)] and write down the change of mercury level [i.e.:- [$\Delta h_{Hg} = 2h$]] with time (time interval must be in seconds).

5. Repeat step (4) but use negative step change [e.g.:- change the valve from position (3) to position (2)].

Calculation

1. Derive Eq.(3) and define the constants as in Eq.(4).
2. Calculate x , *cp* and kp theoretically

Where:- L = 0.48m , = 0.016 kg/m.s , D = 7mm.

3. Plot the theoretical response between H(t) and time derived from equation (4) after introducing a step change in ΔP.
4. Calculate theoretically the following :-

a) Over shoot , b) Decay ratio , c) Rise time , d) Period of oscillation , e) Natural period of oscillation

5. Plot the calibration curc between Q and AP where:-

$\Delta P = \rho g \Delta hHg = \rho g 2h$

6. Plot the actual response of (Δh — Δh_s) versus time for both increasing and decreasing step change (Δh - Δh_s) = (Δh_{Hg} - Δh_{sHg}) / 2 .
7. Calculate experimentally the terms in section (4) of the calculation.

Discussion

Discuss the following:-

- Experimental and theoretical results.
- Effect of *q*> and r on the second order under damped system
- The processes that give second order under damped system

Experiment No (4)
Feedback Control

Object:

The object is to plot the response of the system to a step change in the setting of the out flow pinch valve.

Introduction:-

In this system suggest that the controller should change the flow rate input by amount proportional to the error. The controller is instructed to maintain the flow rate input at the steady state design valve q_s as long as h is equal to h_s as long as (error = zero) if h deviates from h_s causing an error. The controller is to use the magnitude of the error to change the flow rate input proportionality. The deviation of the system from its desired value.

Theory:-

For first order system consider the system shown in Fig.(l) which consists of a tank of uniform cross-sectional area A to which is attached a flow resistance R such as a valve, a pipe are a weir. Assume that q_o the volumetric flow rate (volume/time) through the resistance, is related to the head h by the linear relationship.

$$q_o = \frac{h}{R} \quad \text{...... (1)}$$

A resistance which has this linear relationship between flow and head is referred to as a linear resistance. A time-varying volumetric flow q of liquid of constant density p enters the tank. Determine the transfer function which relates head to flow.

We can analyze this system by writing a transient mass balance around the tank. Rate of mass flow in - Rate if mass flow out = Rate of accumulation

$$q - q_o = A\,\frac{dh}{dt} \quad \text{.......... (2)}$$

Combining Eq.(l) and (2) to eliminate q_o gives the following linear differential equation.

$$q - \frac{h}{R} = A\,\frac{dh}{dt} \quad \text{........ (3)}$$

Procedure:-

1. With the outlet flow valve slightly opened, allow the system to operate until the water level in lower vessel has established, write a note of the water level.

2. Open the pinch valve fully, noting the time and measure the level of water every five seconds until the level has established again (tabulate level (cm) versus time per (sec)).
3. Repeat the experiment this time by suddenly decreasing the opening of the pinch valve so that the water out flow is substantially reduced (this method used for both cases (1) and (2)
4. Plot your measurement on graph with time represented by the horizontal- axis and water level on the vertical axis.

Calculation:-

The system shown in Fig. which consist of tank of uniform cross section area A to which is attached a flow resistance R such as valve, a pipe or weir. Assume that q_{out} volumetric flow rate through the resistance is related to the head h by linear relationship $\mathbf{q_{out}} = \frac{h}{R}$

1. Derive the transfer function of the process using the following equation :

   $q - q_o = \frac{dv}{dt}$ where $q_o = \frac{h}{R}$

2. Derive the theoretical response H(t) to step change in Q_i ($Q_i(s) = \frac{A}{s}$) .
3. Calculate the theoretical time constant **(τtheo)**

   $\boldsymbol{\tau_{theo}}$**= A . R**

   A = $\frac{\pi}{4}$ d^2 ((Radians at the vessel = 5 cm))

   R = $\frac{h_{at\ s.s}}{q_{o\ at\ s.s}}$

4. Plot the theoretical response H(t) time.

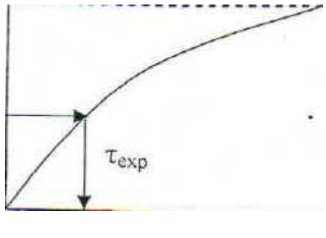
   H(t) = AR $(1 - e^{\frac{-t}{\tau}})$

5. Plot the experimental response H(t) versus time and calculate the experimental time constant.

   H (t) = h - hs

   A’ = A * 0.63

   A = max. Value



6.. Calculate the input flow rate:-

a. Experimentally:

$q_i - q_o = A \frac{dh}{dt}$, q_o = S. h

Plot level (h) versus time (t), obtain $\frac{dh}{dt}$ equal slope for each point.

b. Theoretically:-

Plot level (h) versus time (t), obtain — equal slope for each point.

. q_i = C(G-h) at any time .

Diameter of the vessel = 10cm.

S = 1 valve capacitance.

C = proportionality constant = 20 Cm^2/sec. .

G = steady state level [Final level] (cm) .

h = level at any time.

7. Draw the close – log Response of the liquid level control in a tank .

<u>Discussion:-</u>

Compare and discuss your results experimentally and theoretically.

Experiment No. (5)
Pressure Control

Process Control Technology
Pressure Control PCT-M3

Objective:

The objective is to control pressure level in the tank using pump, valve and the measured value from the pressure transducer.

The PCT-M3

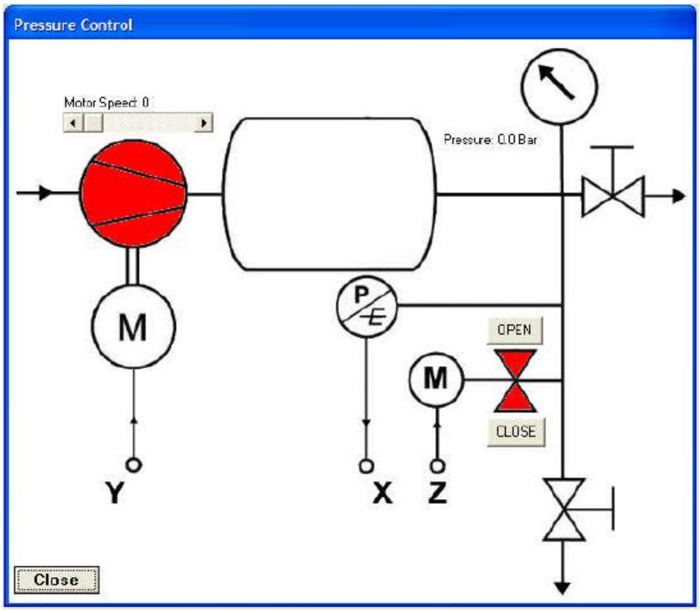
The PCT-M3 consists of a reservoir tank; compressor; control valve; pressure sensor and two needle valves. Control is achieved using the pump, solenoid valve and the pressure transducer to measure the signals. The controller is linked to the PC using a USB connection.

Connecting the PCT-M to the PC

1. Using the supplied USB cable, connect one end to the PCT-M and the other end to the PC.
2. Switch on the PCT-M.
3. Start the software on your computer.
4. There are two menu options in the software, PID Control and Manual Control and there are options for each of the PCT-M units.

Manual Procedure:

1. Selecting the pressure unit in manual mode.



2. Set valve to close.
3. Set the motor speed at a constant value.
4. The pressure record by a stop watch and reading at interval two second until steady state reading reached.
5. The same procedure was repeated for different value of motor speed.
6. Switch the valve (open) to reset the pressure in the tank.

PID Control Procedure:

1. Select the PID control option from software and choose the pressure control.
2. Apply control of proportional (P) by setting the PG only (Set Integral to off (un check box); Set Derivative off (un check box); Set Period to 50).

SP	PG	Delay time	Rise time	Response time
1.5 / 1.0	5			
1.5 / 1.0	10			
1.5 / 1.0	15			
1.5 / 1.0	20			
1.5 / 1.0	40			
1.5 / 1.0	60			
1.5 / 1.0	80			
1.5 / 1.0	100			

SP	PG	Delay time	Rise time	Response time
0.8/0.5	10			
1.0/0.8	10			
1.5 / 1.0	10			
2.0/1.5	10			

3. Click start and when reach the steady state, click stop after this read the rise time, dead time, response time.
4. Repeat the procedure in a PI controller by Change in value of PG and integral for three times to reach the best response..
5. Repeat the procedure in PID controller by Change in value of PG, integral and derivative for three times until reach the best response.
6. Using different type of disturbance (step change, ramp and sine wave).

7. Clicking the Menu button returns to the main screen and resets the pressure Unit.

Discussion:.

1. Plot the response between the pressure and time in manual mode.
2. What conclusions about the nature of 'proportional only control' may be drawn from your observations?
3. What conclusions about the nature of PI control may be drawn from your observations?
4. Why is an integral term in the controller unnecessary?
5. What conclusions about the nature of PID control may be drawn from your observations?
6. Compare between the three controllers P, PI, PID at the best response.

Experiment No. (6)
Temperature Control

Process Control Technology
Temperature Control PCT-M4

Objective:

The objective is to control temperature level in the system using Peltier Heater and measured value from the PRT's.

The PCT-M4

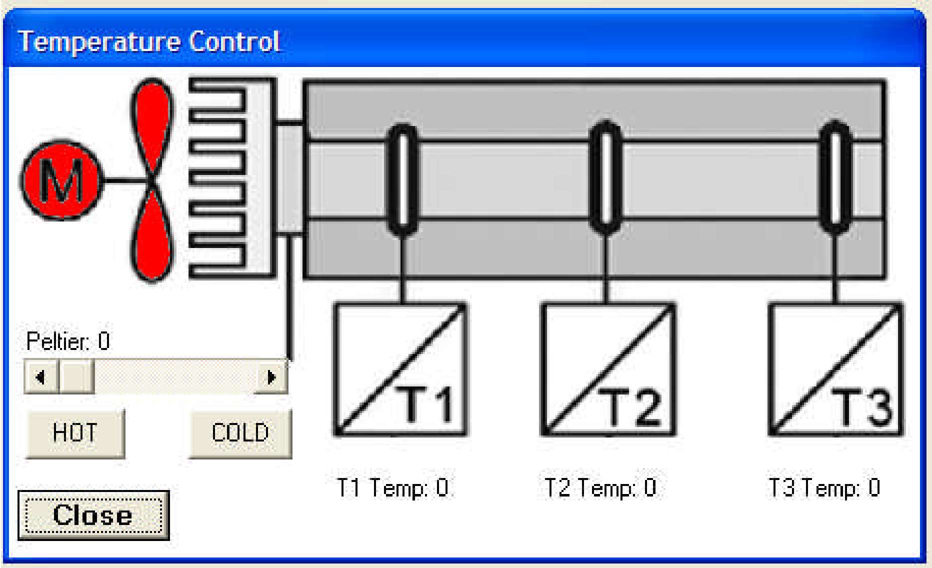
The PCT-M4 consists of Heating Element (TE), Three PT100 PRT Sensors and a Disturbance. Control is achieved using a Peltier Heating Element, and PRT Sensors measure the output. The controller is linked to the PC using a USB connection.

Connecting the PCT-M to the PC

1. Using the supplied USB cable, connect one end to the PCT-M and the other end to the PC.
2. Switch on the PCT-M.
3. Start the software on your computer.
4. There are two menu options in the software, PID Control and Manual Control and there are options for each of the PCT-M units.

Manual Procedure:

1. Selecting the temperature unit in manual mode.



2. Set fan is off.
3. Set the Peltier at a constant value.
4. The three temperature (T1, T2 and T3) record by a stop watch and reading at interval two minutes until steady state reading reached.
5. Switch the fan and record three temperatures by a stop watch and reading at interval two minutes until steady state reading reached.
6. Close the fan.

PID Control Procedure:

1. Select the PID control option from software and choose the temperature control.
2. Apply control of proportional (P) by setting the PG only (Set Integral to off (un check box); Set Derivative off (un check box); Set Period to 50).

SP	PG	Delay time	Rise time	Response time	SP	PG	Delay time	Rise time	Response time
30°C	**5**				**40°C**	**10**			
30°C	**10**								
30°C	**15**				**60°C**	**10**			
30°C	**20**								
30°C	**40**				**80°C**	**10**			
30°C	**60**								
30°C	**80**				**90°C**	**10**			
30°C	**100**								

1. Click start and when reach the steady state, click stop after this read the rise time, dead time, response time.
2. Repeat the procedure in a PI controller by Change in value of PG and integral for three times to reach the best response.
3. Repeat the procedure in PID controller by Change in value of PG, integral and derivative for three times until reach the best response.

4. Clicking the Menu button returns to the main screen and resets the temperature Unit.

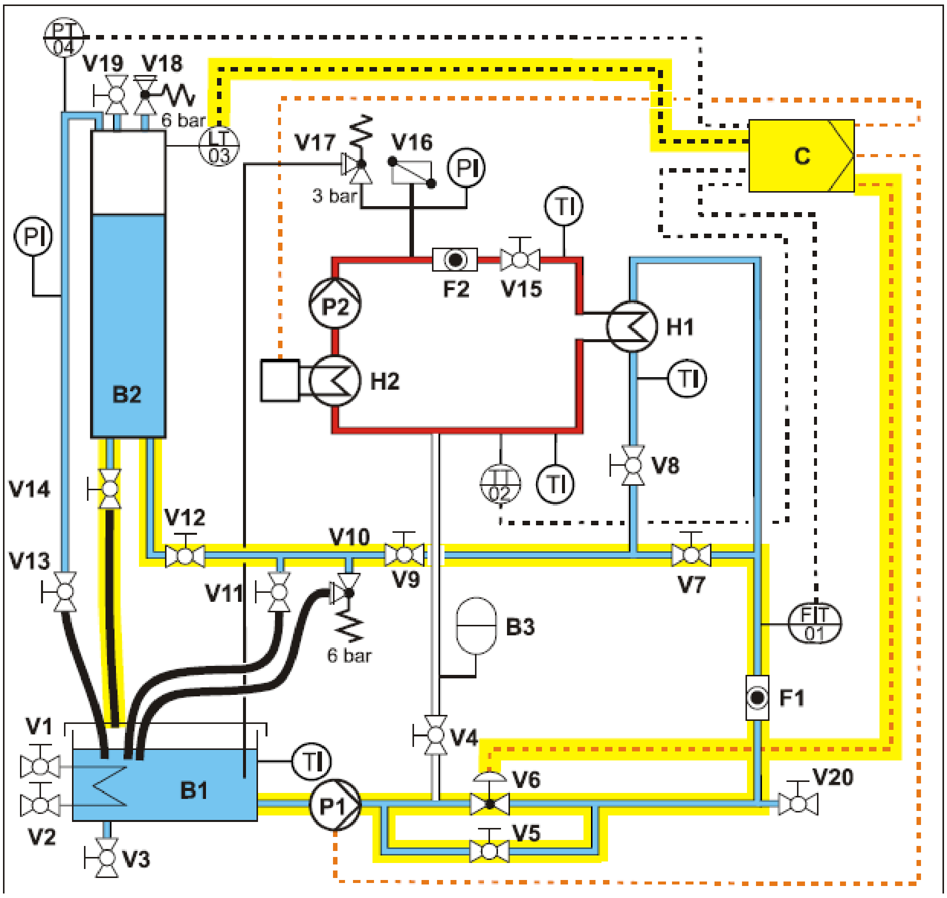
Discussion:.

1. Plot the response between the temperature and time in manual mode.
2. Comparison between using fans and without a fan in manual mode and effect on response.
3. What conclusions about the nature of ‘proportional only control’ may be drawn from your observations?
4. What conclusions about the nature of PI control may be drawn from your observations?
5. Why is an integral term in the controller unnecessary?
6. What conclusions about the nature of PID control may be drawn from your observations?
7. Compare between the three controllers P, PI, PID at the best response.

Experiment No. (7):
Level control in the tank

Objective of the experiment:

The level should be controlled in the open tank (B2) of RT 578. Normal ambient pressure is present in the open tank (B2). The control should be affected with an electro-pneumatic control valve and an industrial controller.



Level control with control valve

Procedure:

1- Open the compressor and set the pressure at 4 bar.

2- Open the computer.

3- Adjust the valves according to the following table:

Valve	V4	V5	V7	V8	V9	V11	V12	V13	V14	V15	V19
Adjustment	closed	closed	open	closed	open	closed	open	open	35°	-	open

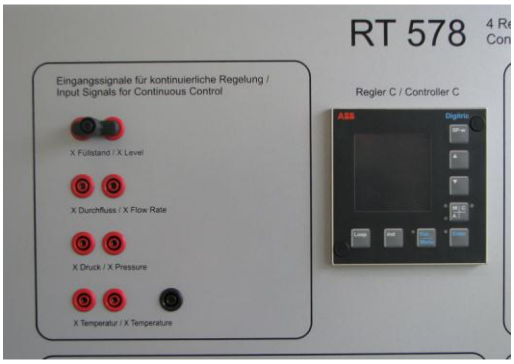
4- Set the switches as following:

Switch for pump P1: manual - 100% (pot)

Switch for control valve V6: control

Switch for heater H2: switched off

Jumper set for level



5- Switch on the device.

6- First, open pump P1 to allow the water to circulate in the device to remove the cavitations from pipes then close pump P1.

7- Choose loop 3 and Direction of control action: inverse (INV) from the device.

8- Start the software on your computer and choose loop 3 in software.

9- Set the reference variable *w*1 to 20%.

10- Set the operating mode in the software from Manual to Auto.

11- Switch on the pump P1.

12- Wait until the level has reached a steady state condition then close valve (V19) to reach steady state response without oscillation.

13- Recording of measured values for continuous as interval sixty seconds.

14- Carry out a step change in the reference variable of:

w1 = 20% ==> w2 = 60%.

15- Change the value of time base graph to 600.

16- Wait until the level has reached at anew steady state.

17- Print graph.

18- Open valve (V19).

19- Close the pump and switch off the device.

NOTE: the following table of the experiment:

Control loop:	loop 3
Jumper:	level
Actuator:	electro-pneumatic control valve
Pump:	manual, 100%
Direction of control action:	inverse (INV)
Controller type:	PID
Kp	0.241
***Tn* in min**	1.136
***Tv* in min**	0.171

Calulations:

1- Drive the transfer function of the level tank.

2- Calculate from each figure the following:

a- Delay time b- Rise time c- Setting time

Discussion:

Discuss the folloing:

1- Discuss the result in figure.

2- Compare between the four controllers P, PI, PD, PID and which is the best for this system.

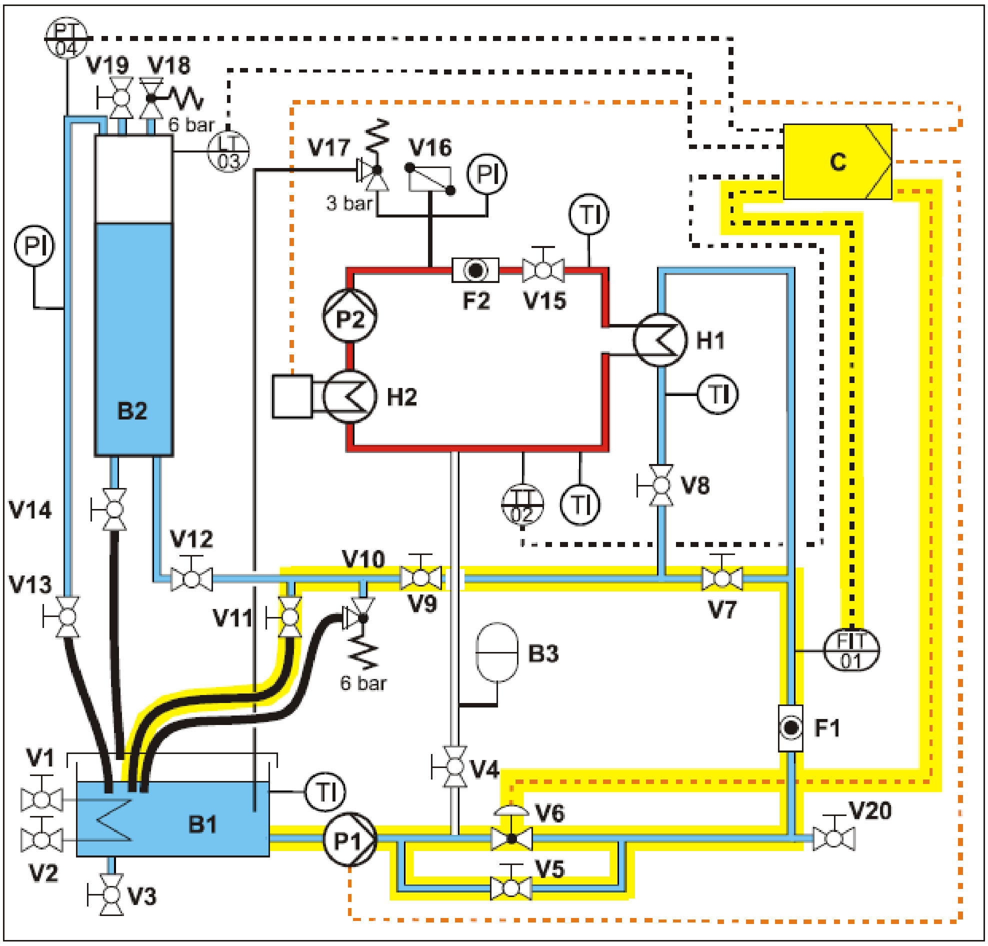
3- Which is the order of the system and why?

4- When decreasing the kp and Tv (τd) is zero what do you think happen in system?

Experiment No. (8):
Flow rate control

Objective of the experiment:

The flow rate in the piping system of RT 578 should be controlled. The control should be affected with an electro-pneumatic control valve and an industrial controller.



Flow rate control with control valve

Procedure:

1- Open the compressor and set the pressure at 4 bar.

2- Open the computer.

3- Adjust the valves according to the following table:

Valve	V4	V5	V7	V8	V9	V11	V12	V13	V14	V15	V19
Adjustment	closed	closed	open	closed	open	open	closed	open	open	-	-

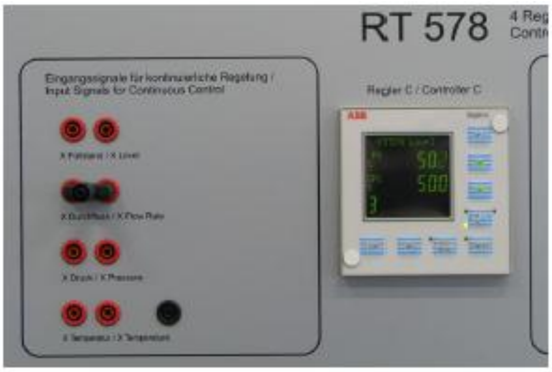
4- Set the switches as follows:

Switch for pump P1: manual - 100% (pot)

Switch for control valve V6: control

Switch for heater H2: switched off

Jumper set for flow rate



5- Switch on the device.

6- First, open pump P1 to allow the water to circulate in the device to remove the cavitations from pipes then close pump P1.

7- Choose loop 3 and Direction of control action: inverse (INV) from the device.

8- Start the software on your computer and choose loop 3 in software.

9- Set the reference variable *w*1 to 10%.

10- Set the operating mode in the software from Manual to Auto.

11- Switch on the pump P1.

12- Wait until the flow rate has reached a steady state condition

13- Recording of measured values for continuous as interval ten seconds.

14- Carry out a step change in the reference variable of:

w1 = 10% ==> w2 = 40%.

15- Change the value of time base graph to 600.

16- Wait until the flow rate has reached at a new steady state.

17- Print graph.

18- Close the pump and switch off the device.

NOTE: the following table of the experiment:

Control loop:	loop 3
Jumper:	Flow rate
Actuator:	electro-pneumatic control valve
Control valve:	manual, 100%
Direction of control action:	inverse (INV)
Controller type:	PID
Kp	2.075
***Tn* in min**	0.073
***Tv* in min**	0.011

Calculations:

3- Drive the transfer function of the flow rate.

4- Calculate from each figure the following:

a- Delay time b- Rise time c- Setting time

Discussion:

Discuss the following:

5- Discuss the result in figure.

6- Comparison between the four controllers P, PI, PD, PID and which is the best for this system.

7- Which is the order of the system and why?

8- When decreasing the kp and Tv (τd) is zero what do you think happened in the system?