# INTERACTING AND NON-INTERACTING SYSTEM

**Instruction manual**

---

**Product Code**

328

---

## Contents

1. Description
2. Specifications
3. Installation requirements
4. Installation Commissioning
5. Troubleshooting
6. Components used
7. Packing slip
8. Warranty
9. Theory
10. Experiments

---

APEX INNOVATIONS
The set up is designed to study dynamic response of single and multi capacity processes when connected in interacting and non-interacting mode. It is combined to study
1) Single capacity process,
2) Non-interacting process and
3) Interacting process.
The observed step response of the tank level in different mode can be compared with mathematically predicted response.
Setup consists of supply tank, pump for water circulation, rotameter for flow measurement, transparent tanks with graduated scales, which can be connected, in interacting and non-interacting mode. The components are assembled on frame to form tabletop mounting.

### Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>Product code</th>
<th>Rotameter</th>
<th>Process tank</th>
<th>Supply tank</th>
<th>Pump</th>
<th>Overall dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td>Interacting and Non interacting system</td>
<td>328</td>
<td>10-100 LPH</td>
<td>Acrylic, Cylindrical, Inside Diameter 92mm</td>
<td>SS304</td>
<td>410Wx350Dx705H mm</td>
</tr>
<tr>
<td><strong>Rotameter</strong></td>
<td>10-100 LPH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Process tank</strong></td>
<td>Acrylic, Cylindrical, Inside Diameter 92mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Supply tank</strong></td>
<td>SS304</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pump</strong></td>
<td>Fractional horse power, type submersible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall dimensions</strong></td>
<td>410Wx350Dx705H mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Shipping details
Gross volume 0.24m³, Gross weight 60kg, Net weight 26kg

### Installation requirements

**Electric supply**
Provide 230 +/- 10 VAC, 50 Hz, single phase electric supply with proper earthing. (Neutral – Earth voltage less than 5 VAC)

- 5A, three pin socket with switch (2 Nos.)

**Water supply**
Distilled water @10 liters

**Support table**
Size: 800Wx800Dx750H in mm
**Installation Commissioning**

**Installation**
- Unpack the box(es) received and ensure that all material is received as per packing slip (provided in instruction manual). In case of short supply or breakage contact Apex Innovations / your supplier for further action.
- Place the set up on table.
- Remove tank fitted at the backside of rotameter bracket and fit it on topside. The outlet of this tank should discharge in left side tank at its bottom.
- Fill distilled water in supply tank (@ 10 lit).
- Place the set up over the supply tank.

**Commissioning**
- Open the rotameter valve and switch on the pump.
- Check the working of rotameter by manipulating flow rates. Recirculate water through rotameter and tanks.

**Troubleshooting**

Note: For component specific problems refer components’ manual

**Components used**

<table>
<thead>
<tr>
<th>Components</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotameter</strong></td>
<td>Make Eureka, Model MG 11, Range 10-100 lph, Connection ¼” BSP back, screwed, Packing PTFE + Silicon</td>
</tr>
<tr>
<td><strong>Pump</strong></td>
<td>Make U.P. National Mfrs. Ltd., Model THS 3000, Type submersible, Head 3 m, 1200 lph discharge, Watts 35, Volts 240 AC, 50Hz</td>
</tr>
</tbody>
</table>

**Packing slip**

<table>
<thead>
<tr>
<th>Box No.1/1</th>
<th>Size W595xD670xH605 mm; Vol:0.24m³</th>
<th>Gross weight: 60 kg Net weight:26 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Set up assembly</td>
<td>1 No</td>
</tr>
<tr>
<td>2</td>
<td>Tool kit</td>
<td>1 No</td>
</tr>
<tr>
<td>3</td>
<td>Set of instruction manuals consisting of: Instruction manual CD (Apex) Coolant pump manual (Rajmane) Eureka’s Loflometer</td>
<td>1 No</td>
</tr>
</tbody>
</table>
Warranty

This product is warranted for a period of 12 months from the date of supply against manufacturing defects. You shall inform us in writing any defect in the system noticed during the warranty period. On receipt of your written notice, Apex at its option either repairs or replaces the product if proved to be defective as stated above. You shall not return any part of the system to us before receiving our confirmation to this effect.

The foregoing warranty shall not apply to defects resulting from:
- Buyer/ User shall not have subjected the system to unauthorized alterations/additions/modifications.
- Unauthorized use of external software/interfacing.
- Unauthorized maintenance by third party not authorized by Apex.
- Improper site utilities and/or maintenance.

We do not take any responsibility for accidental injuries caused while working with the set up.
Step response of single capacity system

Step function: Mathematically, the step function of magnitude A can be expressed as
\[ X(t) = A \ u(t) \] where \( u(t) \) is a unit step function.
It can be graphically represented as

To study the transient response for step function, consider the system consisting of a tank of uniform cross sectional area \( A_1 \) and outlet flow resistance \( R \) such as a valve. \( q_o \), volumetric flow rate through the resistance, is related to head \( h \) by a linear relationship
\[ q_o = h/R \] -------(1)
Writing a transient mass balance around the tank:
Mass flow in - Mass flow out = rate of accumulation of mass in the tank.
\[ q(t) - q_o(t) = d((Ah)/dt \] \( q(t) - q_o(t) = A_1 \ dh/dt \) -------(2)
Combining equation (1) and (2) to eliminate \( q_o(t) \) gives the following linear differential equation:
\[ q - h/R = A_1 \ dh/dt \] -------(3)
Initially the process is operating at steady state, which means that \( dh/dt = 0 \). Therefore equation (3) becomes as
\[ q_s - h_s/R = 0 \] -------(4)
Where, the subscript \( s \) indicates the steady state value of the variable.
Subtracting equation (4) from (3)
\[ q - q_s = 1/R ( h - h_s) + A_1 \ d(h - h_s)/ dt \] -----(5)
Defining deviation variable
q - q_s = Q
h - h_s = H
Equation (5) can be written as
Q = 1/R H + A1 dH/dt ---------(6)
Taking a transform of equation (6) gives
Q(s) = 1/R H(s) + A1s H(s) ----(7)
Equation (7) can be rearranged into standard form of first order system as
H(s)/Q(s) = R/(τs +1) -----------(8)
Where τ = A1R
For a step change of magnitude A, we can write
Q(t) = A u(t)
So Q(s) = A/s
From equation (8) we can write
H(s) = A/s {R/(τs +1)} ---------(9)
So by taking Laplace transform of equation (9) we get,
H(t) = AR { (1- e^{-t/τ}) } ---------(10)
Step response of first order systems arranged in non-interacting mode

In non-interacting system we assume the tanks have uniform cross sectional area and the flow resistance is linear. To find out the transfer function of the system that relates $h_2$ to $q$, writing a mass balance around the tanks, we proceed as follows.

We can write mass balance at tank 1 as

$$q - q_1 = A_1 \left( \frac{dh_1}{dt} \right) \quad \text{(1)}$$

A mass balance at tank 2 is given as

$$q_1 - q_2 = A_2 \left( \frac{dh_2}{dt} \right) \quad \text{(2)}$$

The flow head relationships for the two linear resistances in non-interacting system are given by the expressions

$$q_1 = \frac{h_1}{R_1} \quad \text{(3)}$$

$$q_2 = \frac{h_2}{R_2} \quad \text{(4)}$$

From (1) and (3)

$$\frac{Q_1(s)}{Q(s)} = \frac{1}{\tau_{1s} + 1} \quad \text{(5)}$$

Where $Q_1 = q_1 - q_{1s}$, $Q = q - q_s$ and $\tau_1 = A_1 R_1$

From (2) and (4)

$$\frac{H_2(s)}{Q(s)} = \frac{R_2}{\tau_{2s} + 1} \quad \text{(6)}$$

Where

$$H_2 = h_2 - h_{2s} \quad \text{and} \quad \tau_2 = A_2 R_2$$

Overall transfer function can be calculated as follows

$$\frac{H_2(s)}{Q(s)} = \frac{A \times R_2}{\tau_{1s} \times \tau_{2s} + 1 \times (\tau_{2s} + 1)} \quad \text{...(7)}$$

For a step change of magnitude $A$

$$Q(t) = A \ u(t)$$

So, $Q(s) = \frac{A}{s}$

$$H_2(s) = \frac{A \times R_2}{s \times (\tau_{1s} + 1) \times (\tau_{2s} + 1)} \quad \text{...(8)}$$

$H_2$ at time $t$ is given by

$$\frac{1}{\tau_1 \times \tau_2}$$
\[ H_2(t) = A R_2 \left[ 1 - \frac{e^{-t/\tau_1}}{\tau_1} - \frac{e^{-t/\tau_2}}{\tau_2} \right] \] ...

**To study impulse response of first order systems arranged in non-interacting mode**

Mathematically, the impulse function of magnitude A is defined as
\[ X(t) = A \delta(t) \]
Where \( \delta(t) \) is the unit impulse function. Graphically it can be described as

Overall transfer function of the system as described in previous experiment
\[ \frac{H_2(s)}{Q(s)} = \frac{R_2}{\left( \tau_1 s + 1 \right) \left( \tau_2 s + 1 \right)} \] ...

For a impulse change of magnitude V (volume added to the system)
\[ Q(t) = V \delta(t) \]
So, \[ Q(s) = \frac{V}{R_2} \]
\[ H_2(s) = \frac{V x R_2}{\left( \tau_1 s + 1 \right) \left( \tau_2 s + 1 \right)} \] ...

For impulse change \( H_2 \) at time t is given by
\[ e^{-t/\tau_1} - e^{-t/\tau_2} \]
\[ H_2(t) = V R_2 \left[ e^{-t/\tau_1} - e^{-t/\tau_2} \right] \] ...

Considering non-linear resistance at outlet valve of the tank \( R_2 \) can be calculated as
\[ R_2 = \frac{2dH_2}{dQ} \]
Where \( dH_2 \) is change in level of tank2 and \( dQ \) is change of flow from initial to final state.

Put the values in equation (3) to find out \( H(t) \) Predicted and plot the graph of \( H(t) \) Predicted and \( H(t) \) Observed Vs time.
**Step response of first order systems arranged in interacting mode**

Assuming the tanks of uniform cross sectional area and valves with linear flow resistance the transfer function of interacting system can be written as:

\[
\frac{H_2(s)}{Q(s)} = \frac{R_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2) s + 1}
\]

Let

\[
b = \frac{1}{\tau_1} + \frac{1}{\tau_2} + \frac{A_1 R_2}{\tau_1 \tau_2}
\]

\[
\alpha = \frac{-b}{2} + \sqrt{\left(\frac{b}{2}\right)^2 - \left(\frac{1}{\tau_1 \tau_2}\right)}
\]

\[
\beta = \frac{-b}{2} - \sqrt{\left(\frac{b}{2}\right)^2 - \left(\frac{1}{\tau_1 \tau_2}\right)}
\]

For a step change of magnitude \(A\)

\[
H_2(t) = AR_2 \left\{ 1 - \frac{1}{(1/\alpha - 1/\beta)} \left[ (1/\alpha) e^{(\alpha t)} - (1/\beta) e^{(\beta t)} \right] \right\}
\]

In terms of transient response the interacting system is more sluggish than the non-interacting system.
**Impulse response of first order systems arranged in interacting mode**

As mentioned in theory part of experiment 3, impulse function is described as

\[ X(t) = A \delta(t) \]

Overall transfer function of the system as described in previous experiment

\[ \frac{H_2(s)}{Q(s)} = \frac{R_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2) s + 1} \] ........(1)

For an impulse change of magnitude \( V \) (volume added to the system)

\[ Q(t) = V \delta(t) \]

So, \( Q(s) = V \)

\[ \frac{H_2(s)}{R_2} = \frac{V}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2) s + 1} \] ........(2)

For impulse change \( H_2 \) at time \( t \) is given by

\[ H_2(t) = \frac{V R_2}{(\alpha - \beta)} [e^{\alpha t} - e^{\beta t}] \] ........(3)

(For \( \alpha, \beta \) refer theory part of experiment No. 4)

Considering non-linear valve resistance, the resistance at outlet of both tanks can be calculated as

\[ R_1 = 2 \frac{dH_1}{dQ} \] ........(4)

\[ R_2 = 2 \frac{dH_2}{dQ} \] ........(5)
1 Step response of single capacity system

Procedure
- Start up the set up.
- A flexible pipe is provided at the rotameter outlet. Insert the pipe in to the cover of the top Tank 1. Keep the outlet valves (R1 & R2) of the Tank 1 & Tank 2 slightly closed.
- Switch on the pump. Adjust rotameter flow rates in steps of 10 LPH from 50 to 100 LPH and note steady state levels for Tank 1 against each flow rate.
- From the data obtained select a suitable band for experimentation. (Say 90-100 LPH in which we are getting more readings of tank level).
- Adjust the flow rate at lower value of the band selected (say 90 LPH) and allow the level of the Tank 1 to reach the steady state and record the flow and level at steady state.
- Apply the step change by increasing the rotameter flow by @ 10 LPH.
- Immediately start recording the level of the Tank 1 at the interval of 15 sec, until the level reaches at steady state.
- Carry out the calculations as mentioned in calculation part and compare the predicted and observed values of the tank level.
- Repeat the experiment by throttling outlet valve (R1) to change resistance.

Observations
Diameter of tank mm: ID 92 mm
Initial flow rate (LPH):
Initial steady state tank level (mm):
Final flow rate (LPH):
Final steady state tank level (mm):
(Fill up columns H(t) observed and H(t) predicted after calculations)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time (sec)</th>
<th>Level (mm)</th>
<th>H(t) observed (mm)</th>
<th>H(t) predicted (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations
\[ H(t)_{\text{observed}} = (\text{Level at time } t - \text{level at time 0}) \times 10^{-3} \text{ m} \]
\[ H(t)_{\text{predicted}} = AR \left\{ (1- e^{-t/\tau}) \right\} \]
Where
- \( H(t)_{\text{predicted}} \) is level predicted at time \( t \) in m.
- \( A = \) magnitude of step change
  - \( = \) Flow after step input - Initial flow rate in m\(^3\)/sec.
- \( R = \) Outlet valve resistance in sec/m\(^2\)
Considering non linear resistance at outlet, it can calculated as \( R = \frac{dH}{dQ} \)
Where \( dH \) is change in level (Final steady state level - Initial steady state level) and \( dQ \) is change flow (Final flow rate after step change - Initial flow rate).
\[ \tau = \text{time constant in sec.} \]
\[ = A1 \times R \] Where \( A1 \) is area of tank in m\(^2\) and \( R \) is resistance of outlet.
valve in sec/m^2
A1 = Area of tank = π/4 (Diameter of tank in m)^2

t = Time in sec from initial steady state.

Plot the graph of H(t) Vs time for observed and predicted levels.

**Sample calculations & results**
Refer MS Excel program for calculation and graph plotting.

**Comments**
Observed response fairly tallies with theoretically calculated response. Deviations observed may be due to following factors:
- Non-linearity of valve resistance.
- Step change is not instantaneous.
- Visual errors in recording observations.
- Accuracy of rotameters.
2 Step response of first order systems arranged in non-interacting mode

Procedure

- Start up the set up.
- A flexible pipe is provided at the rotameter outlet. Insert the pipe in to the cover of the top Tank 1. Keep the outlet valves (R1 & R2) of both Tank 1 & Tank 2 slightly closed. Ensure that the valve (R3) between Tank 2 and Tank 3 is fully closed.
- Switch on the pump and adjust the flow to @90 LPH. Allow the level of both the tanks (Tank 1 & tank 2) to reach at steady state and record the initial flow and steady state levels of both tanks.
- Apply the step change with increasing the rotameter flow by @ 10 LPH.
- Record the level of Tank 2 at the interval of 30 sec, until the level reaches at steady state.
- Record final flow and steady state level of Tank1
- Carry out the calculations as mentioned in calculation part and compare the predicted and observed values of the tank level.
- Repeat the experiment by throttling outlet valve (R1) to change resistance.

Observations

Diameter of tanks: ID 92mm
Initial flow rate (LPH):
Initial steady state level of Tank 1 (mm):
Initial steady state level of Tank 2 (mm):
Final flow rate (LPH):
Final steady state level of Tank 1 (mm):
Final steady state level of Tank 2 (mm):

(Fill up columns H(t) observed and H(t) predicted after calculations)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time (sec)</th>
<th>Level of tank 2 (mm)</th>
<th>H(t) observed (mm)</th>
<th>H(t) predicted (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations

\[
H(t)_{\text{observed}} = (\text{Level at time } t - \text{level at time } 0) \times 10^{-3} \\
H(t)_{\text{predicted}} = A R_2 \left[1 - \frac{t}{\tau_2} \left\{ - \frac{e^{-t/\tau_1}}{\tau_1} - \frac{e^{-t/\tau_2}}{\tau_2} \right\} \right] \text{---(1)}
\]

Where

- \(H(t)_{\text{predicted}}\) is level in Tank2 predicted at time \(t\) in m.
- \(A = \text{magnitude of step change}\)
- \(A = \text{Flow after step input} - \text{Initial flow rate in m}^3/\text{sec.}\)
- \(\tau_1 = A_1 \times R_1\)
- \(\tau_2 = A_2 \times R_2\)

Area of tank 1 = \(\pi/4 \times (d_1^2)\) in \(m^2\)
Area of tank 2 = \(\pi/4 \times (d_2^2)\) in \(m^2\)

Considering non-linear resistance at outlet valve of both tanks, it can be calculated as
\[ R_1 = \frac{dH_1}{dQ} \]
\[ R_2 = \frac{dH_2}{dQ} \]

Where \( dH_1 \) is change in level of tank 1 and \( dQ \) is change flow of from initial to final state and \( dH_2 \) is change in level of tank 2 at initial and final state.

Put the values in equation (1) to find out \( H(t)_{\text{Predicted}} \) and plot the graph of \( H(t)_{\text{Predicted}} \) and \( H(t)_{\text{Observed}} \) Vs time.

**Sample calculations & results**

Refer MS Excel program for calculation and graph plotting.

**Comments**

Observed response fairly tallies with theoretically calculated response. Deviations observed may be due to following factors:

- Non-linearity of valve resistance.
- Step change is not instantaneous.
- Visual errors in recording observations.
- Accuracy of rotameters.
3 Impulse response of first order systems arranged in non-interacting mode

**Procedure**
- Start up the set up.
- A flexible pipe is provided at the rotameter outlet. Insert the pipe in to the cover of the top tank (T1). Keep the outlet valves (R1 & R2) of both Tank1 & Tank2 slightly closed. Ensure that the valve (R3) between two bottom tanks T2 and T3 is fully closed.
- Switch on the pump and adjust the flow to @90 LPH. Allow the level of both Tank1 and Tank 2, to reach the steady state and record the initial flow and steady state levels of both tanks.
- Apply impulse input by adding 0.5 lit of water in Tank 1.
- Record the level of the Tank 2 at the interval of 30 sec, until the level reaches to steady state.
- Record final steady state level of Tank1
- Carry out the calculations as mentioned in calculation part and compare the predicted and observed values of the tank level.
- Repeat the experiment by throttling outlet valve (R1) to change resistance.

**Observations**
Diameter of tanks: ID 92mm
Initial flow rate (LPH):
Initial steady state tank 1 level (mm):
Initial steady state tank 2 level (mm):
Volume added (lit.):
Final steady state tank 1 level (mm):
Final steady state tank 2 level (mm):
(Fill up columns H(t) observed and H(t) predicted after calculations)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time (sec)</th>
<th>Level of tank 2 (mm)</th>
<th>H(t) observed (mm)</th>
<th>H(t) predicted (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculations**
\[
H(t)_{observed} = (\text{Level at time } t - \text{ level at time } 0) \times 10^{-3} \\
H_2(t)_{Predicted} = V R_2 \left[ \frac{1-e^{-t/\tau_2}}{\tau_1-\tau_2} \right]
\]
\[
V = \text{Volume of liquid added as an impulse input (in m}^3)\]
(For \(\tau_1, \tau_2\) and R2 refer values obtained in experiment 2)

Put the values in above equation to find out \(H(t)_{Predicted}\) and plot the graph of \(H(t)_{Predicted}\) and \(H(t)_{Observed}\) Vs time.

**Sample calculations & results**
Refer MS Excel program for calculation and graph plotting.

**Comments**
Observed response fairly tallies with theoretically calculated response. Deviations observed may be due to following factors:
- Non-linearity of valve resistance.
- Impulse is not instantaneous.
- Visual errors in recording observations.
- Accuracy of rotameters.
4 Step response of first order systems arranged in interacting mode

**Procedure**
- Start up the set up.
- A flexible pipe is provided at the rotameter outlet. Insert the pipe in to the cover of the Tank 3. Keep the outlet valve (R2) of Tank 2 slightly closed. Ensure that the valve (R3) between Tank 2 and Tank 3 is also slightly closed.
- Switch on the pump and adjust the flow to @90 LPH. Allow the level of both Tank 2 and Tank 3, to reach the steady state and record the initial flow and steady state levels of both tanks.
- Apply the step change with increasing the rotameter flow by @ 10 LPH.
- Record the level of the Tank 2 at the interval of 30 sec, until the level reaches at steady state.
- Record final steady state flow and level of Tank 3
- Carry out the calculations as mentioned in calculation part and compare the predicted and observed values of the tank level.
- Repeat the experiment by throttling outlet valve (R1) to change resistance.

**Observations**
- Diameter of tanks: ID 92mm
- Initial flow rate (LPH):
- Initial steady state level of Tank 3 (mm):
- Initial steady state level of Tank 2 (mm):
- Final flow rate (LPH):
- Final steady state level Tank 3 (mm):
- Final steady state level Tank 2 (mm):

(Fill up columns H(t) observed and H(t) predicted after calculations)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time (sec)</th>
<th>Level of tank 2 (mm)</th>
<th>H(t) observed (mm)</th>
<th>H(t) predicted (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calculations**

\[ H(t)_{\text{Observed}} = (\text{Level at time } t - \text{level at time } 0) \times 10^{-3} \text{ m} \]

\[ (H_2) t_{\text{Predicted}} = AR_2 \left\{ 1 - \frac{e^{\alpha t}}{1 - e^{\beta t}} \right\} \quad \text{---(1)} \]

Where
- \( A = \text{magnitude of step change} \)
- \( \tau_1 = A_1 \times R_1 \)
- \( \tau_2 = A_2 \times R_2 \)

Where \( \tau_1 \) is time constant of tank1, \( A_1 \) is area of tank1 and \( R_1 \) is resistance of outlet valve of tank1.

\( \tau_2 \) is time constant of tank2, \( A_2 \) is area of tank2 and \( R_2 \) is resistance of outlet valve of tank2.

Considering non linear resistance at outlet valve of both tanks, it can calculated as

\( R_1 = \frac{dH_1}{dQ} \) and \( R_2 = \frac{dH_2}{dQ} \)

Where \( dH \) is change in tank height for change in flow \( dQ \). Calculate values of \( b, \alpha \) and \( \beta \) from equations given in theory part.

Put the values in equation (1) to find out \( H(t)_{\text{Predicted}} \) and plot the graph of \( H(t)_{\text{Predicted}} \) and \( H(t)_{\text{Observed}} \) Vs time.
**Sample calculations & results**
Refer MS Excel program for calculation and graph plotting.

**Comments**
Observed response fairly tallies with theoretically calculated response. Deviations observed may be due to following factors:
- Non-linearity of valve resistance.
- Step change is not instantaneous.
- Visual errors in recording observations.
- Accuracy of rotameters.
5 Impulse response of first order systems arranged in interacting mode

Procedure
- Start up the set up.
- A flexible pipe is provided at the rotameter outlet. Insert the pipe into the cover of Tank 3. Keep the outlet valve (R2) of Tank 2 slightly closed. Ensure that the valve (R3) between both Tank 2 and Tank 3 is slightly closed
- Switch on the pump and adjust the flow to @90 LPH. Allow the level of both the tanks to reach at steady state and record the initial flow and steady state levels.
- Apply impulse input by adding 0.5 litre of water in Tank 3.
- Record the level of the Tank 2 at the interval of 30 sec, until the level reaches to steady state.
- Record final steady state level of Tank 3.
- Carry out the calculations as mentioned in calculation part and compare the predicted and observed values of the tank level.
- Repeat the experiment by throttling outlet valve (R1) to change resistance.

Observations
Diameter of tanks: ID 92mm
Initial flow rate (LPH): 
Initial steady state tank 3 level (mm):
Initial steady state tank 2 level (mm):
Volume added (lit): 
Final steady state tank 3 level (mm):
Final steady state tank 2 level (mm):
(Fill up columns H(t) observed and H(t) predicted after calculations)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Time</th>
<th>Level of tank 2</th>
<th>H(t) observed</th>
<th>H(t) predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(sec)</td>
<td>(mm)</td>
<td>(mm)</td>
<td>(mm)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculations

H(t) observed = (Level at time t - level at time 0) x 10\(^{-3}\)
\[ H_2(t) \text{ Predicted} = \frac{V R_2}{\tau_1 (e^{\alpha t} - e^{\beta t})} \]

V = Volume of liquid added as an impulse input (in m\(^3\))
(For calculating \(\tau_1, \tau_2, \alpha, \beta\) and R2 refer experiment 3)
Put the values in above equation to find out H(t) Predicted and plot the graph of H(t) Predicted and H(t) Observed Vs time.

Sample calculations & results
Refer MS Excel program for calculation and graph plotting.

Comments
Observed response fairly tallies with theoretically calculated response. Deviations observed may be due to following factors:
- Non-linearity of valve resistance.
- Impulse is not instantaneous.
- Visual errors in recording observations.
- Accuracy of rotameters.