Process Control Engineering (19CH5DCPCE)

Laboratory Manual

5th Semester
Department of Chemical Engineering
(Accredited by Washington accord Tier 1)

BMS COLLEGE OF ENGINEERING
BENGALURU-19
(Autonomous College under VTU)

Faculty In charge :

Department of Chemical engineering, BMSCE

Department of Chemical Engineering

Process Control Engineering Manual
2017

Name of the Student:

USN:

Faculty In-charge:

LABORATORY CERTIFICATE

This is to certify that **Ms./Mr.** has satisfactorily completed the course of experiments in Practical ***Process Control Engineering*** prescribed by the Visvesvaraya Technological University, Belgaum, for **V Semester Chemical Engineering** course in the laboratory of the college in the year 2021.

Head of the Department

Staff In-charge of the Batch

Date:

Marks	
Maximum	Obtained
10	

Name of the Candidate:

USN:

Signature of the Candidate

DEPARTMENT OF CHEMICAL ENGINEERING

Process Control Engineering

Laboratory Manual

List of Experiments

Sl. No.	Title of the Experiment	Date	Page No.
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Time Constant Determination of a Thermometer

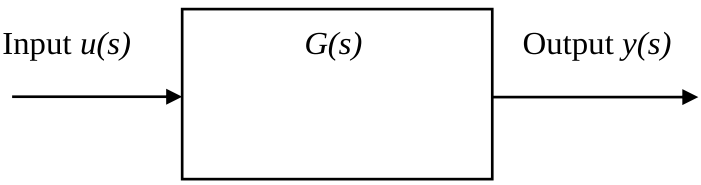
Aim:

(a) Determination of the response to the step input for a thermometer.

(b) Experimental determination of its time constant.

Apparatus: Experimental setup, stop watch, thermometer.

Theory: The simplest possible dynamic system is one which satisfies a first order, linear, differential equation. Such a system is known as a "first order system". A block diagram representation of the system is given below.



The value of time constant will determine how quickly the system moves toward steady state. The heat exchange between the thermometer and the measured medium takes time. That is why there is always a delay in time in the registration of the actually prevailing temperature in temperature measurement.

The response time is the time, which is needed by the thermometer after a temperature jump to indicate a certain part of the temperature jump.

A thermometer's response time depends on various factors

• Heat transfer values from thermometer to water or oil

• Heat transfer values in the structure of the thermometer

• Constructive structure of thermometer (geometry)

• Flow velocity of measured medium

• Heat transfer from measured medium to thermometer

• Heat capacity of measured medium

• Immersion depth of thermometer

• Heat capacity of thermometer and material

The unsteady and steady state mass balance equations are written and solved to obtain the response which is of the form,

$$Y(t) = A(1 - e^{t/\tau}) \quad (1)$$

Where τ is the time constant, $\tau = \frac{MC_P}{UA}$, here M is the mass of mercury, C_p is the specific heat of mercury, U is the overall heat transfer coefficient and A is the heat transfer area.

Procedure:

1. The stirrer as well as the heater is switched on and the thermometer is placed in the water bath.
2. Temperature is allowed to reach the steady state and the temperature is noted down. The room temperature is also noted down.
3. The thermometer is then removed from the bath and is allowed to cool to the room temperature.
4. Once this is done, the thermometer is placed in the water bath again and immediately the stop watch is started.
5. The temperature begins to rise rapidly and for every 5 seconds the time is noted down until it reaches a steady state value.
6. The observations of this system are noted down.
7. Next a test tube filled with oil is placed inside the water bath and allowed to attain steady state. Once the temperature of the test tube is steady, a thermometer is immediately placed inside the test tube and the stop watch is started simultaneously.
8. The temperature begins to rise rapidly. Time is noted down for every 5 seconds until it reaches a steady state value.

Table 1: Observations

Sl. No.	**Water filled tube**		**Oil filled tube**	
	Time, *t* [s]	**Temperature [^{o}C]**	**Time, *t* [s]**	**Temperature [^{o}C]**
1				
2				
5				

Model Calculations:

$$\%\ \text{change} = \left(\frac{T_i - T_o}{T_n - T_o}\right) \times 100 \tag{2}$$

where,

T_o = Room Temp = Initial Temperature of Thermometer

T_n = Bath Temp = Final Temperature of Thermometer

T_i **=** Current Temperature of Thermometer

1) For water
2) For oil

Graph:

- Plot a graph of % change vs. time in order to determine τ for both water and oil.
- $\%\ \text{change} = \left(\frac{T_i - T_o}{T_n - T_o}\right) \times 100$

Table 2: Results

Sl. No.	**Water filled tube**			**Oil filled tube**		
	Time, *t* [s]	**Temperature [^{o}C]**	**% change in Temp**	**Time, *t* [s]**	**Temperature [^{o}C]**	**% change in Temp**
1						
2						
3						
4						

Nature of Graphs:

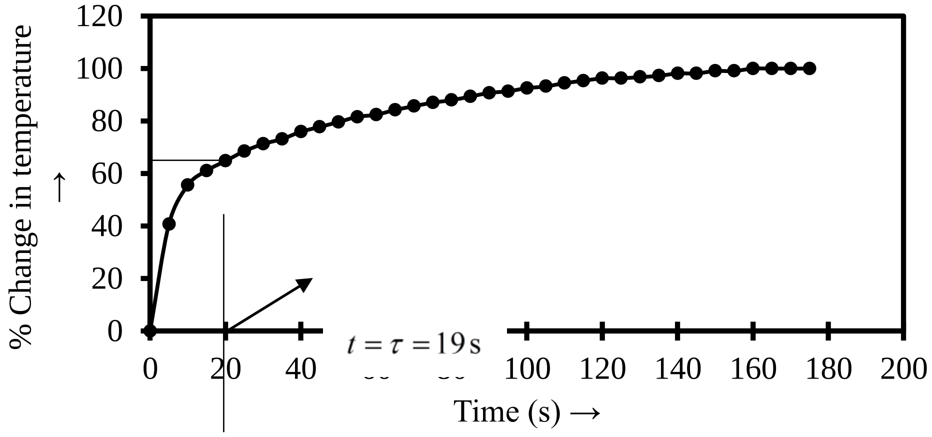


Figure 1: % Change in temperature vs time (in oil)

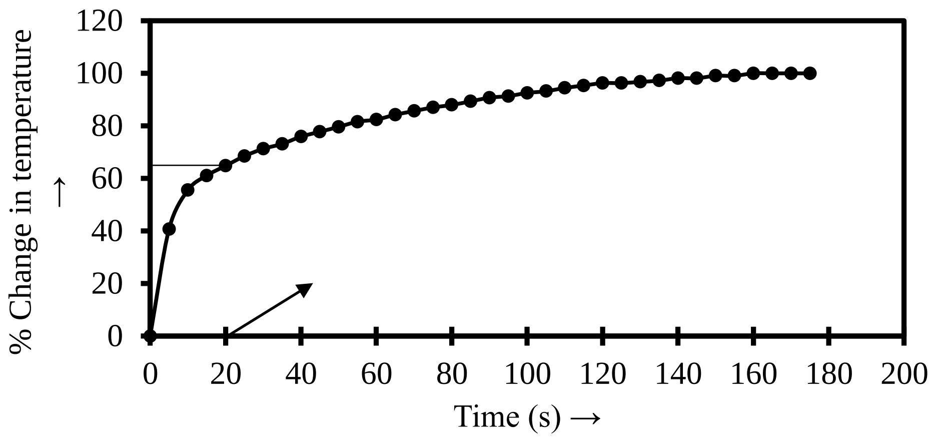


Figure 2:% Change in temperature vs time (in water)

Results:

The response to a step input for the given thermometer was observed and plotted. The time constants (τ) of the given thermometer were experimentally determined. τ for water =   s and τ for oil =   s.

INFERENCE:

DYNAMICS OF A SECOND ORDER UNDERDAMPED: SYSTEM U-TUBE MANOMETER

Aim:-

To study the dynamic behavior of a U-tube manometer and to determine the properties like overshoot, decay ratio, rise time, period and natural frequency.

Apparatus:-

Experimental Setup, Stopwatch.

Theory:-

The dynamic behaviour of the U-tube liquid manometer with equal diameter columns corresponds to an under-damped dynamic system. Improving the dynamic response (decreasing the overshoot and the settling time, increasing the phase and delay margins) can be achieved by increasing the connection tube length, by decreasing the columns diameter and by using a high density liquid manometer

A system which can be represented by a linear second order differential equation is called as a second order system. A U-Tube Manometer is a second order system. In many applications the pressure difference to be measured may vary with time. The response time of the measuring instrument and the connecting tubes decide the response time.

On applying force balance and solving the obtained equation, we get the transfer function for this second order system as

$$G(s) = \frac{Y(s)}{X(s)} = \frac{k}{\tau^2 S \quad + 2\tau\varepsilon S + 1} \qquad (1)$$

Where

k = Gain

$\tau =$ Characteristic time

$\varepsilon =$ Damping Factor or Damping Coefficient

G(s) is the transfer function of the system under consideration

The dynamic behavior of the U-tube liquid manometer with equal diameter columns corresponds to an under-damped dynamic system. Improving the dynamic response (decreasing the overshoot and the settling time, increasing the phase and delay margins) can be achieved by increasing the connection tube length, by decreasing the columns diameter and by using a high density liquid manometer

Procedure:-

1. Put on the vacuum pump and adjust the system to a particular vacuum.
2. Set the manometer level to zero by operating the valve above the manometer.
3. Press the solenoid valve and note down the trough and peak made by the oscillations and respective time required.
4. Repeat the procedure for different vacuum pressure.
5. Plot the response curve and note down the overshoot, decay ratio, frequency etc.

Observation table:-

Table 1: Observations for pressure = 300 mmHg

Sl. No.	Time (s)	Manometer reading (mm)	% change
1			
2			
3			

Table 2 : Observations for pressure = 400 mmHg

Sl. No.	Time (s)	Manometer reading (mmHg)	% change
1			
2			
3			

Table 3 : Observations for pressure = 500 mmHg

Sl. No.	Time (s)	Manometer reading (mmHg)	% change
1			
2			
3			
5			

Specimen Calculations:-

For 300 mmHg:

$$\text{Overshoot} = \frac{A}{B} \qquad (3)$$

$$\text{Overshoot} = \exp\left(\frac{-\pi\xi}{\sqrt{1-\xi^2}}\right) \qquad (4)$$

$$= \exp\left(\frac{-\pi\xi}{\sqrt{1-\xi^2}}\right)$$

$$\text{Decay Ratio} = \left(\frac{A}{B}\right)^2 \qquad (5)$$

(6)

$$\text{Cyclical Frequency} = f = \frac{1}{T}$$

From the graph, T =

f = s^{-1}

Rise Time from the graph = s

Response Time from the graph = s

Nature of Graphs:-

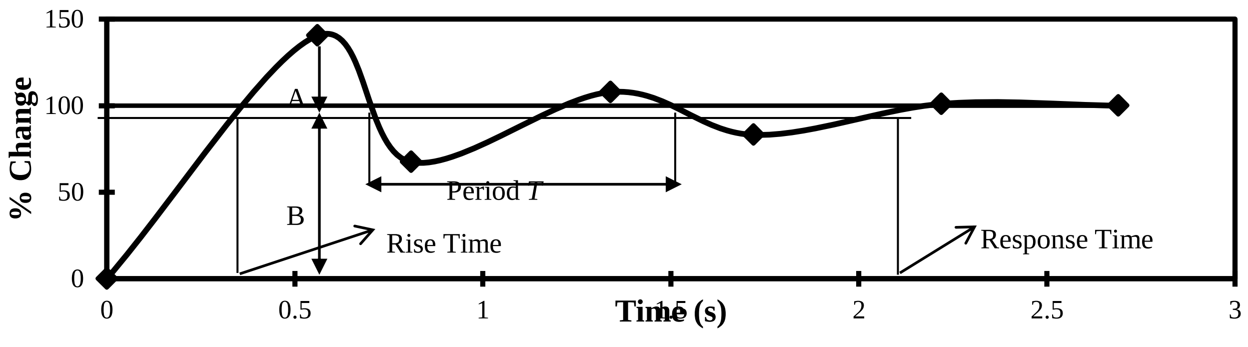


Figure 3: %change vs. time for 300 mmHg

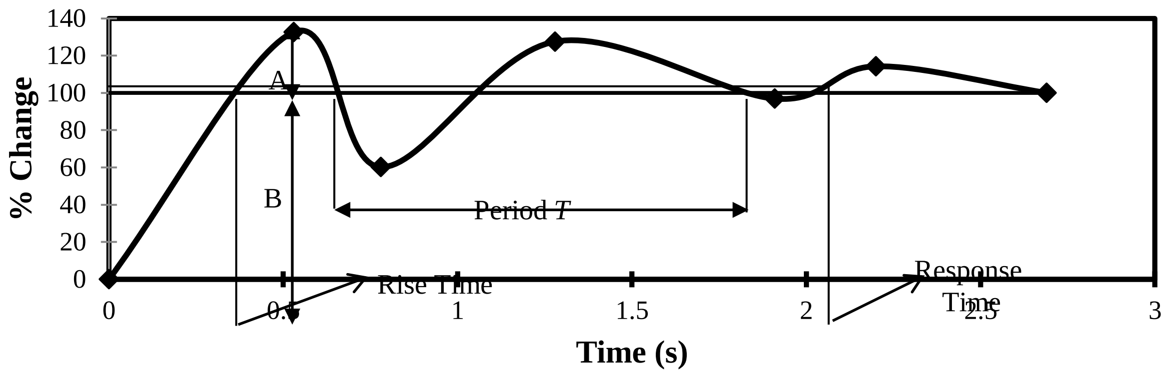


Figure 4: %change vs. time for 400 mmHg

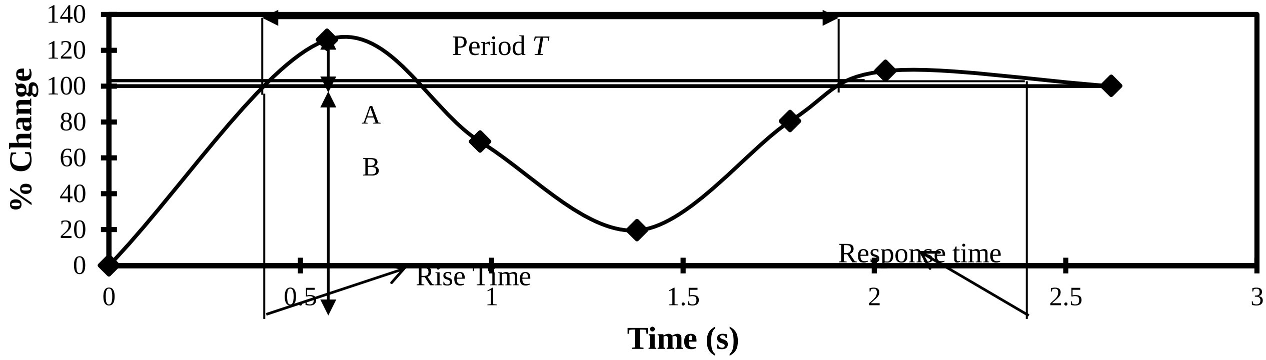


Figure 5: %change vs. time for 500 mmHg

Table 4: Results

Sl. No.	Pressure (mm Hg)	Overshoot (*A/B*)	Decay Ratio	Time Period (*T*)	Frequency (*F*)	Rise Time, s [*D*]	ξ	Response Time, s [*C*]
1.	300							
2	400							
3	500							

Results of experiment:

The dynamic behavior of a U tube manometer has been studied and properties such as overshoot, decay ratio, cyclic frequency, damping factor, rise time and response time has been determined.

Non-Interacting Tanks

Aim:

To study the dynamics and compare the theoretical response with the actual response for a step input to a two-tank, non-interacting system.

Apparatus:

Experimental setup, bucket, stopwatch and measuring flask.

Theory:

A non-interacting tank system includes two liquid tanks arranged in series with a linear resistance attached to the outlet of each tank. When water or any fluid is introduced into the system, it behaves as a second order system. The transfer function is developed as follows:

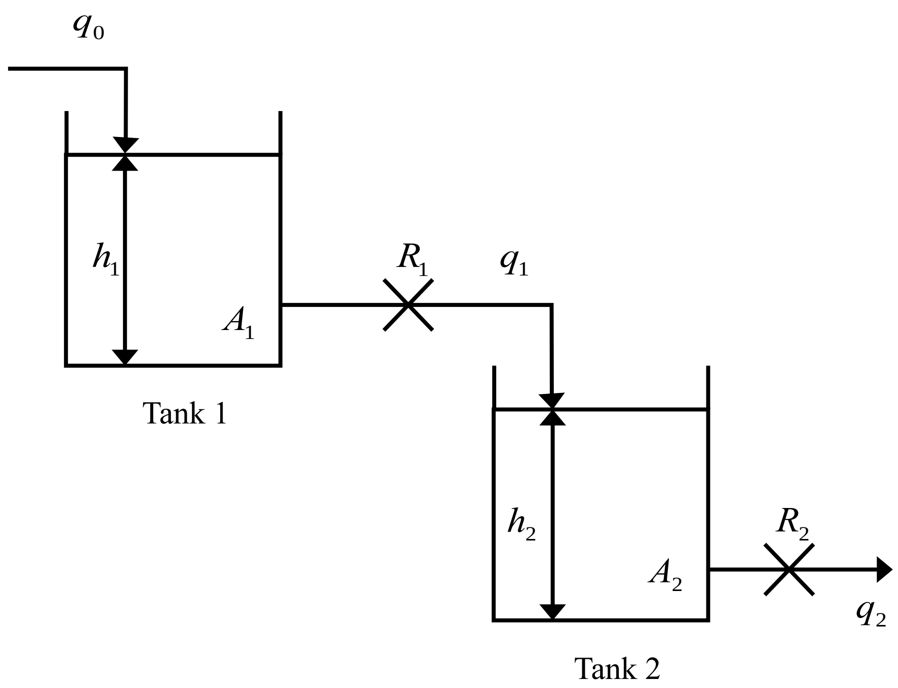


Figure 1: Two tank non-interacting system

Consider two tanks, tank 1 and tank 2 with resistances R_1 and R_2 arranged in series. When the outflow from tank 1 is discharged into the atmosphere before entering tank 2 and the flow through R_1 depends only on level h_1 and is independent of the level in tank 2 the system is known as a non-interacting system. This implies that the variation in level h_2 does not affect the transient response occurring in tank 1. Consider the two tanks in series as shown in the figure above handling a liquid of constant density. It is assumed that these tanks:

1. Have uniform cross-sectional area, A_1 and A_2 respectively
2. Have linear flow resistances

Since the resistances are linear, the outflow rate can be written in terms of the resistances as

$$Q_1 = \frac{h_1}{R_1}$$

$$Q_2 = \frac{h_2}{R_2}$$

Since these two systems do no interact, we can consider them as two individual first order systems. Hence we obtain the desired transfer functions as:

$$\frac{H_2(s)}{Q_0(s)} = \frac{R_2}{(1+\tau_1 s)(1+\tau_2 s)} = \frac{R_2}{\tau_1\tau_2 s^2 + (\tau_1+\tau_2)s + 1}$$

Formulae:

Height of liquid in tank, $h = h' \times \sin\alpha$ (1)

Deviation Variable, $H = h - h_s$ (2)

Volumetric flow rate, $q = \dfrac{\text{Water collected in Tank}}{10} \times 10^{-6}$ (3)

Deviation Variable, $Q = q - q_s$ m^3/s (4)

Time constant, $\tau = A \times R$ (5)

Theoretical response for step change,

$$\%\left[\frac{H_2}{MR_2}\right]_{\text{Theoretical}} = \left[1 - \left[\left(\frac{\tau_1\tau_2}{\tau_1-\tau_2}\right)\times\left[\frac{e^{-t/\tau_1}}{\tau_2} - \frac{e^{-t/\tau_2}}{\tau_1}\right]\right]\right]\times 100 \tag{6}$$

Experimental response for step change,

$$\%\left[\frac{H_2}{MR_2}\right]_{\text{Experimental}} = \left[\frac{H_2}{MR_2}\right]\times 100 \tag{7}$$

Procedure:

Part A: Determination of resistances and capacitances of the system.

1) The dimensions of both the tanks are measured.
2) The cross sectional areas of tanks A_1 and A_2 are the capacitances C_1 and C_2 respectively.
3) The inlet valve is kept fully open and the bypass valve is kept slightly open.

4) The pump is then switched on and the system is allowed to reach steady state (when there is no variation in the height of the tanks) and the levels in the two tanks are noted down.
5) The steady state flow rates are noted by collecting water for a known duration of time.
6) The above procedure is repeated by gradually opening the bypass valve till its fully open.
7) A graph of level v/s height for both tanks is plotted and the slopes determined give the values for resistances R_1 and R_2.
8) The product of the resistance and capacitance gives the time constants t_1 and t_2.

Part B: Determination of time constant from response study for a step change in the input flow rate.

1) A low flow rate is maintained and the level in tank 2 is noted with the corresponding flow rate.
2) This is the initial steady state condition at time $t = 0$. The flow rate is now increased at a stretch by opening the bypass valve for a higher flow rate.
3) The stopwatch is started and the change in the level of tank 2 with time is noted.
4) The change is constantly noted down till the conditions become steady and the percentage change in level of tank 2 plotted against time. This is the required experimental response curve.
5) The theoretical percentage change is calculated using formula (6) and the curve is plotted.

Part A:

Table 1: Observations for steady state flow

Sl.no	Rotameter reading (LPM)	Tank 1 slant height, h_1 (mm)	Tank 2 slant height, h_2 (mm)	Water collected in tank 1 (mL)	Water collected in tank 2 (mL)	Time (s)
1	5					
2	10					
3	15					

4	20						
5	25						
6	30						
7	35						
8	40						

Model Calculations:

1) Height of liquid in tank 1, $h_1 = h_1^{'} \times \sin\alpha =$

2) Height of liquid in tank 2, $h_2 = h_2^{'} \times \sin\alpha =$

3) Deviation Variables, $H_1 = h_1 - h_{s1} =$

   $H_2 = h_2 - h_{s2} =$

4) Volumetric flow rate

   $$q_1 = \frac{\text{Water collected in Tank 1}}{10}$$

   $$q_2 = \frac{\text{Water collected in Tank 2}}{10}$$

5) Deviation Variables, $Q_1 = q_1 - q_{s1} =$ m^3/s

   $Q_2 = q_2 - q_{s2} =$ m^3/s.

Table 2: Results for steady state flow

Sl.no	**Height, h_1 (mm)**	**Height, h_2 (mm)**	**Deviation Variable, H_1 (mm)**	**Deviation Variable, H_2 (mm)**	**Flow rate, q_1 (m^3/s)**	**Flow rate, q_2 (m^3/s)**	**Deviation Variable, Q_1 ($m^3.s$)**	**Deviation Variable, Q_2 (m^3/s)**
1								
2								
3								
4								
5								

1) Tank resistances,

   R_1 = Slope of H_1 v/s Q_1 curve =

$$R_2 = \text{Slope of } H_2 \text{ v/s } Q_2 \text{ curve} =$$

2) Tank capacitances (C/S Area),

$$A_1 = \qquad \text{m}^2$$

$$A_2 = \qquad \text{m}^2$$

3) Time constants,

$$\tau_1 = A_1 \times R_1 = \qquad \text{s}$$

$$\tau_2 = A_2 \times R_2 = \qquad \text{s}$$

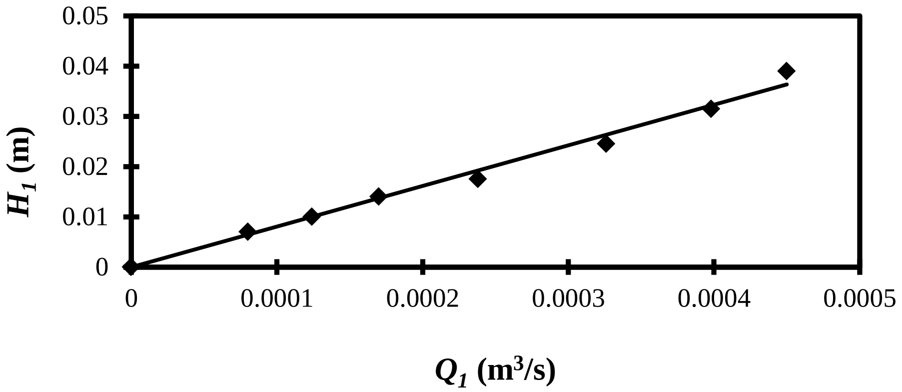


Figure 2*: H Vs Q* for tank

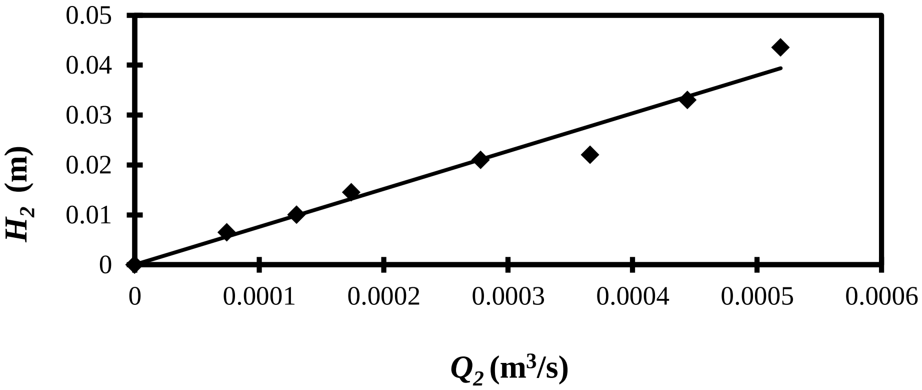


Figure 3: H *Vs* Q for tank 2

Part B:

Table 3: Observations for step input

Sl.no	**Time** (s)	**Tank 2 slant height,** $h_2^{'}$ (mm)
1		
2		
3		
4		
5		

Model Calculations:

1) Height of liquid in tank 2,

$$h_2 = h_2^{'} \times \sin\alpha =$$

Deviation Variable, $H_2 = h_2 - h_{s2} =$

2) Magnitude of step change,

$$M = \qquad \text{LPM} .$$

3) Response for step change,

$$\%\left[\frac{H_2}{MR_2}\right]_{\text{Theoretical}} = \left[1 - \left[\left(\frac{\tau_1\tau_2}{\tau_1 - \tau_2}\right) \times \left[\frac{e^{-t/\tau_1}}{\tau_2} - \frac{e^{-t/\tau_2}}{\tau_1}\right]\right]\right] \times 100$$

Table 4: Results for step response

Sl.no	**Time** (s)	**Height,** h_2 (mm)	**Deviation variable,** H_2 (mm)	$\left(\frac{H}{mR}\right)_{\exp}$ (%)	$\left(\frac{H}{mR}\right)_{theo}$ (%)
1	0				
2	5				
3	10				
4	15				
5	20				
8	35				
9	40				

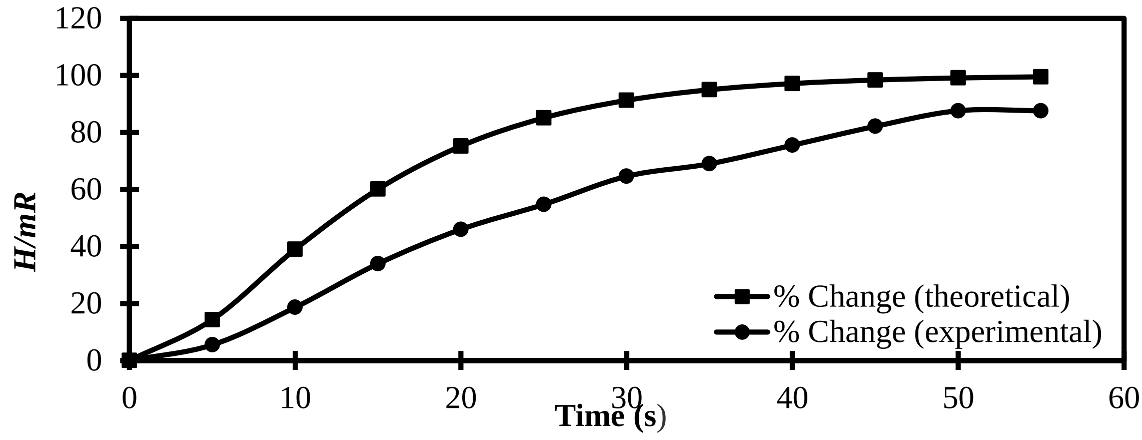


Figure 6: Theoretical and experimental step responses v/s time

Results:

The dynamics of the two tank, non-interacting system has been studied. The theoretical and actual responses are compared for a step change in input and have been tabulated.

Inference:

SINGLE TANK SYSTEM

Aim:

To determine the time constant of a single tank system by

(i) evaluating the resistance and capacitance of the system.

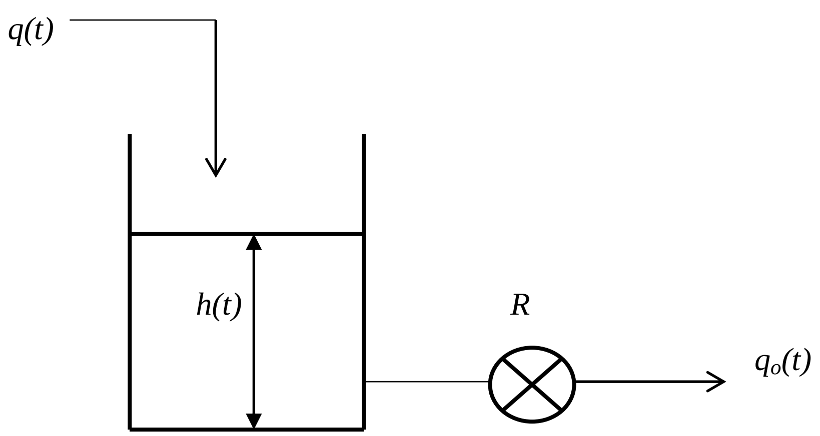
(ii) from the response study to a step change in the inlet flow rate and to compare them.

Apparatus:

Stop watch, Experimental setup, measuring jar, bucket.

Theory:

A single tank system is one which consists of a liquid level tank of constant cross sectional area with a linear resistance attached near the outlet. When such a system is made to undergo a step change in the input flow rate of liquid, the system behaves as a first order system. Consider a single tank system as shown below in the figure. The tank has a uniform cross sectional area '*A*' where a liquid is flowing into the tank at volumetric flow rate $q(t)$ and flowing out at volumetric flow rate $q_o(t)$ through a resistance R such as valve. The density of the liquid flowing through the tank is assumed to be constant.



A first order system is characterized by a capacity to store material, energy or momentum and the resistance associated with the flow of mass, energy or momentum reaching the capacity. If a step input is applied to a capacity-dominated process such as a single tank, the output begins to change instantaneously but does not reach its steady state value for a period of time.

The time constant defined as the amount of time it takes to reach 63.2 % of its steady-state value. For a single tank

$$\tau = A \times R$$

The transfer function of the given system can be written as

$$\frac{H(s)}{Q(s)} = \frac{R}{\tau s + 1}$$

$$\frac{Q_o(s)}{Q(s)} = \frac{1}{\tau s + 1}$$

Procedure:

Determination of resistance and capacitances of the system

1. Measure the dimensions of the tank. The cross-sectional area of the tank is the capacitance *C*.
2. Keep the inlet valve fully open and the bypass valve slightly open.
3. Switch on the pump and wait for the steady state to be reached.
4. Note down the level in the tank and also the corresponding steady state flow rate by collecting water for known duration of time.
5. Repeat the above procedure by gradually opening the bypass valve till it is fully open.
6. Plot a graph of level vs height in the tank and determine the slope which is the resistance R1. The product of the resistance and capacitance gives the time constant τ_1.

Determination of the time constant from response study for a step change in the inlet flow rate

1. Maintain a low flow rate and note down the level in the tank after steady rate is reached and the corresponding flow rate. This is the initial steady state condition at time $t = 0$.
2. Now increase the flow rate at a stretch by opening the bypass valve for a higher flow rate and simultaneously start the stop watch. Note down the change in the level of the tank with time.
3. Continue noting down till the condition becomes steady.
4. Plot percentage change in the level in the tank vs time which is the required experimental response curve. Calculate theoretical percentage change and plot the curve.

Observations:

Table 1: Steady State Response

Sl. No.	Rotameter Reading (Lpm)	Time (s)	Volume (mL)	Height *h'* (mm)
1				
2				
3				
4				
5				

Model Calculation:

1. Volumetric flow rate (q) = $\frac{\text{Volume}}{\text{Time}}$

q = m^3/s

2. $h_{act} = h_{slant} \times \sin\alpha$

3. Deviation Variable $H_1 = h_1 - h_s =$ m

Area of Tank 1 =

Area of Tank 2 =

Table 2: Results for Part A

Sl. No.	Rotameter Reading (lpm)	Volume of water collected (m^3/s)	Time (s)	$Q = q - q_s$ (m^3/s)	Height *h'* (mm)	$h = h'\sin 30$ (m)	$H = h - h_s$ (m)
1	5						
2	10						
3	15						
4	20						
5	25						
6	30						
7	35						
8	40						

Part B : Observations

Table 3: Step Response

Sl. No.	Time (s)	Height (*h*’) (mm)
1		
2		
3		
4		
5		
6		
7		
8		
9		

Model Calculations:

1. $h_{act} = h_{slant} \times \sin\alpha$
2. $m =$ Final rotameter reading − Initial rotameter reading

   $m =$ Lpm
3. $\tau = R \times A$

   $\tau =$ s
3. $\left(\dfrac{H(t)}{mR}\right)_{\exp}$

   $\left(\dfrac{H(t)}{mR}\right)_{\exp} =$

   $\%\left(\dfrac{H(t)}{mR}\right)_{\exp} =$ %
4. $\left(\dfrac{H(t)}{mR}\right)_{thep} = 1 - e^{\frac{=t}{\tau}}$

   $\left(\dfrac{H(t)}{mR}\right)_{theo} =$

$$\%\left(\frac{H(t)}{mR}\right)_{theo} = \qquad \%$$

Table 4 : Results for Part B

SL. NO.	**Time (*s*)**	**Height(*h*') (*m*) ×10^3**	**Vertical Height *h*=*h*'sin*α* (*m*)**	***H*=*h*-*h*$_s$ (*m*)**	$\left(\frac{H(t)}{mR}\right)_{theo}$ **(%)**	$\left(\frac{H(t)}{mR}\right)_{exp}$ **(%)**
1						
2						
3						
4						
5						

Nature of Graphs:

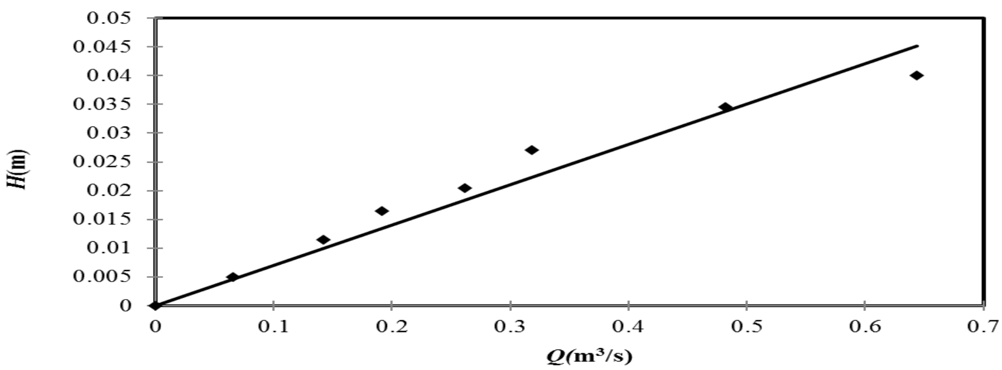


Figure 2: H vs Q

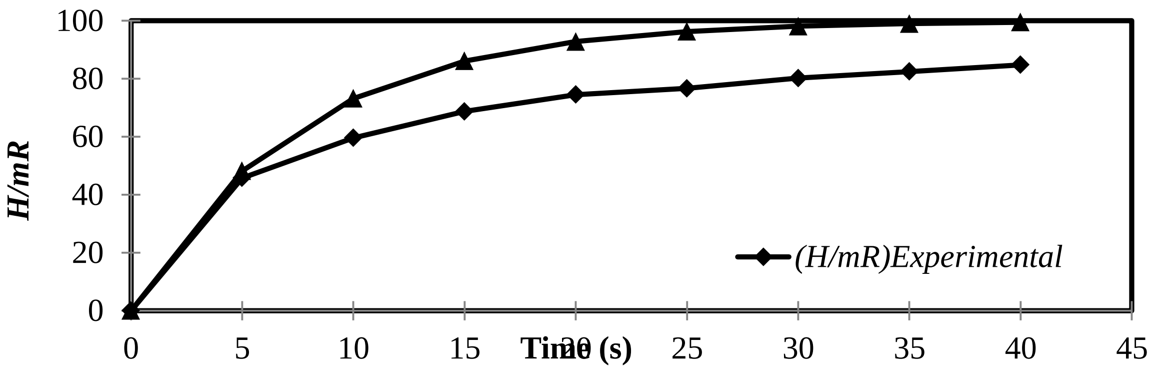


Figure 3: Theoretical and Experimental step responses v/s time

Result:

The time constant of a single tank system was calculated by evaluating the resistance and capacitance of the tank and it was found to be s.

The time constant was also determined from the response study to a step change in the inlet flow rate and the values were compared. It was found that the theoretical values were greater than the experimental values

Inference:

Interacting Tanks

Aim:

To study the dynamics and compare the theoretical response with the actual response for a step input to a two-tank, interacting system.

Apparatus:

Experimental setup, bucket, stopwatch and measuring flask.

Theory:

A two tank system arranged in series such that the liquid level in tank 2 is dependent on the level in tank 1 is known as an interacting tank system. Such a system behaves as a complex second order system. When this system is subjected to a step change in the input, the corresponding transfer function is derived as follows:

Consider two tanks, tank 1 of uniform cross sectional area A_1 with a linear resistance R_1 and tank 2 of uniform cross sectional area A_2 with a linear resistance R_2.

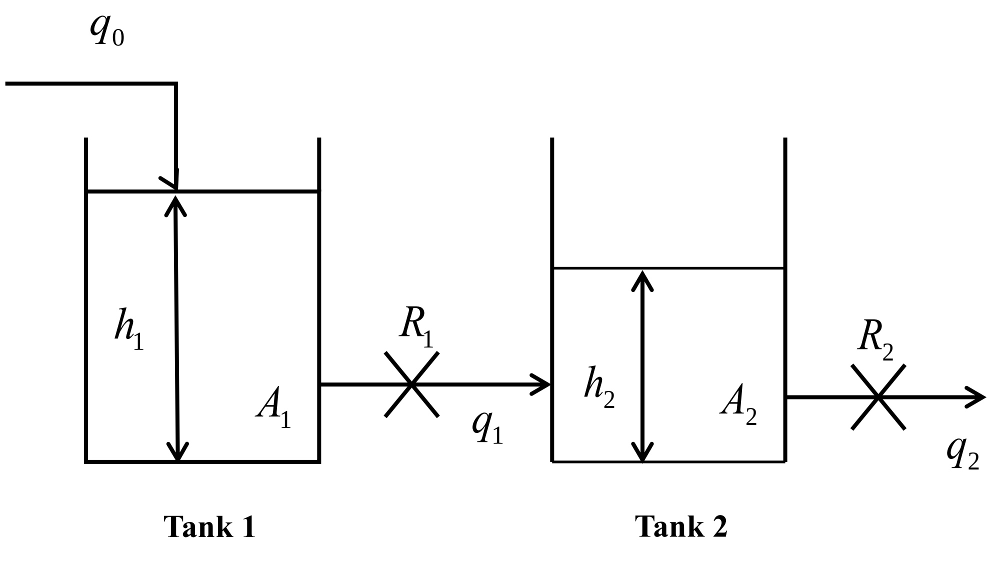


Figure 1 : Two tank interacting system

When the outflow from tank 1 is directly discharged through R_1 into tank *2* without being discharged into the atmosphere, flow through R_1 depends on the difference between h_1 and h_2.Since the outflow of the liquid from tank 1 is dependent on the height of liquid in tank *2,* such a system is known as an interacting system

The mass balance equation for the above system yields,

$$A_1 \frac{dh_1}{dt} = q_0 - q_1$$

$$A_2 \frac{dh_2}{dt} = q_1 - q_2$$

The linear resistances to flow are obtained from,

$$q_1 = \frac{h_1 - h_2}{R_1}$$

$$q_2 = \frac{h_2}{R_2}$$

Introducing deviation variables to the above equations and solving them, we get the transfer function,

$$\frac{H_2(s)}{Q_0(s)} = \frac{R_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2)s + 1}$$

Where, $\tau_1 = A_1 R_1$ and $\tau_2 = A_2 R_2$.

For a step change in input, the roots of the denominator of the above equation (RHS) need to be calculated. Let the roots be p_1 and p_2. We get,

$$\tau_1 \tau_2 (s - p_1)(s - p_2) = 0$$

Let $-p_1 = 1/\tau_a$ and $-p_2 = 1/\tau_b$ where τ_a, τ_b are the effective time constants.

The above equation yields,

$$\tau_1 \tau_2 \left(s + 1/\tau_a\right)\left(s + 1/\tau_b\right) = 0$$

Deriving the response of the above equation at $\tau_a \neq \tau_b$ yields, (M= Magnitude)

$$\%\left[\frac{H_2}{MR_2}\right]_{Theoretical} = \left[1 - \left[\left(\frac{\tau_a \tau_b}{\tau_a - \tau_b}\right)\left[\frac{e^{-t/\tau_a}}{\tau_b} - \frac{e^{-t/\tau_b}}{\tau_a}\right]\right]\right] 100$$

Procedure:

Part A: Determination of resistances and capacitances of the system.

9) The dimensions of both the tanks are measured.

10) The cross sectional areas of tanks A_1 and A_2 are the capacitances C_1 and C_2 Respectively.
11) The inlet valve is kept fully open and the bypass valve is kept slightly open.
12) The pump is then switched on and the system is allowed to reach steady state (when there is no variation in the height of the tanks) and the levels in the two tanks are noted down.
13) The steady state flow rate of tank 2 is noted by collecting water for a known duration of time.
14) The above procedure is repeated by gradually opening the bypass valve till it's fully open.
15) Graphs of level v/s flow rate are plotted and the slopes determined give the values for resistances R_1 and R_2.
16) The product of the resistance and capacitance gives the time constant (t_1, t_2).

Part B: Determination of time constant from response study for a step change in the input flow rate.

6) A low flow rate is maintained and the level in tank 2 is noted with the corresponding flow rate.
7) This is the initial steady state condition at time $t = 0$. The flow rate is now increased at a stretch by opening the bypass valve for a higher flow rate.
8) The stopwatch is started and the change in the level of tank 2 with time is noted.
9) The change is constantly noted down till the conditions become steady and the percentage change in level of tank 2 plotted against time. This is the required experimental response curve.
10) The theoretical percentage change is calculated using formula (6) and the curve is plotted.

Part A:

Table 1 : Observations for steady state flow

Sl.no	Rotameter (LPM)	Tank 1 slant height, h_1' (mm)	Tank 2 slant height, h_2' (mm)	Water collected in tank 2 (mL)	Time (s)
1					
2					
3					
4					
5					

Model Calculations:

Height of liquid in tank 1, $h_1 = h_1' \times \sin a =$

Height of liquid in tank 2, $h_2 = h_2' \times \sin a =$

- Deviation Variables, $H_1 = h_1 - h_{s1} =$

$H_2 = h_2 - h_{s2} =$

- Volumetric flow rate for tank 2,

$$q_2 = \frac{\text{Water collected in Tank 2}}{10} = \qquad \text{m}^3/\text{s}.$$

- Deviation Variable,

$Q_2 = q_2 - q_{s2} =$

Table 2 : Results for steady state flow

Sl.no	Height, h_1 (mm)	Height, h_2 (mm)	Deviation Variable, H_1 (m)	Deviation Variable, H_2 (m)	Flow rate, q_2 (m^3/s)	Deviation Variable, Q_2 (m^3/s)	H_1-H_2 (m)
1							
2							
3							
4							
5							

- Tank resistances,

$$R_1 = \text{Slope of } H_1 - H_2 \text{ v/s } Q_2 \text{ curve} =$$

$$R_2 = \text{Slope of } H_2 \text{ v/s } Q_2 \text{ curve} =$$

- Tank capacitances (C/S Area),

$$A_1 = \qquad \text{m}^2$$

$$A_2 = \qquad \text{m}^2$$

- Time constants,

$$\tau_1 = A_1 \times R_1 = \qquad \text{s}$$

$$\tau_2 = A_2 \times R_2 = \qquad \text{s}$$

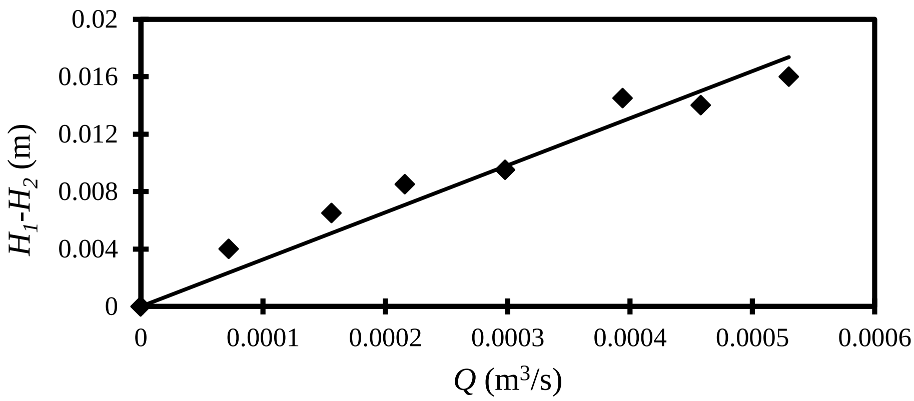


Figure 2 : Plot of (H_1-H_2) vs Q_2

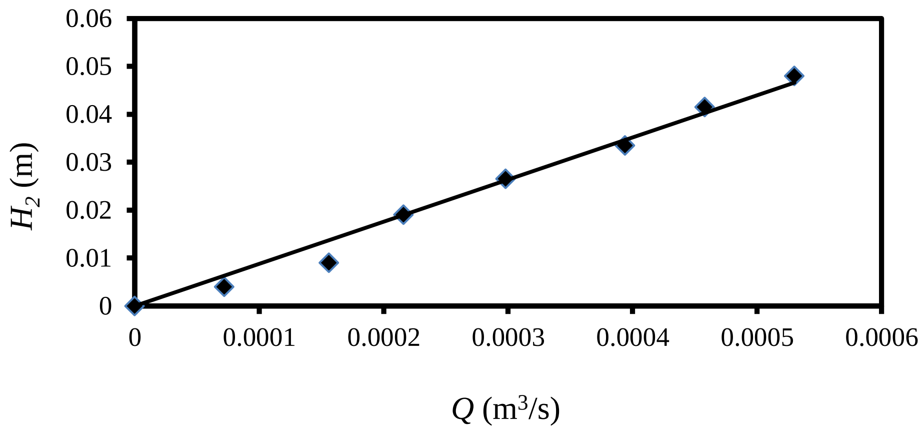


Figure 3 : Plot of H_2 vs Q_2

Part B:

Table 4 : Observations for step response

Sl.no	**Time** (s)	**Tank 2 slant height,** h_2 (mm)
1	0	
2	5	
3	10	
4	15	
5	20	

Model Calculations:

1) Height of liquid in tank 2,

$$h_2 = h_2' \times \sin\alpha =$$

2) Deviation Variable, $H_2 = h_2 - h_{s2} = .$

3) Magnitude of step change,

$$M = \quad \text{LPM} .$$

4) Effective time constants,

$$\tau_1\tau_2 s^2 + (\tau_1 + \tau_2 + A_1 R_2)s + 1 = (2.924 \times 7.79)s^2 + (2.924 + 7.79 + (0.087 \times 76.92))s + 1$$

$$= 22.778s^2 + 18.77s + 1 \Rightarrow p_1 = -0.05707, p_2 = -0.767$$

$$-p_1 = 1/\tau_a \Rightarrow \tau_a = 1/-p_1 = 1/-(-0.05707) = 17.52\,\text{s}$$

$$-p_2 = 1/\tau_b \Rightarrow \tau_b = 1/-p_2 = 1/-(-0.767) = 1.304\,\text{s}.$$

5) Response for step change,

$$\%\left[\frac{H_2}{MR_2}\right]_{Theoretical} = \left[1 - \left[\left(\frac{\tau_a\tau_b}{\tau_a - \tau_b}\right) \times \left[\frac{e^{-t/\tau_a}}{\tau_b} - \frac{e^{-t/\tau_b}}{\tau_a}\right]\right]\right] \times 100$$

$$\%\left[\frac{H_2}{MR_2}\right]_{Experimental} = \qquad \%$$

Table 5 : Results for Part B

Sl.no	Time (s)	Height, $h_2 = h_2' \times sin\alpha$ (mm)	Deviation variable, H_2 (mm)	$\left(\frac{H}{mR}\right)_{exp}$ (%)	$\left(\frac{H}{mR}\right)_{theo}$ (%)
1					
2					
3					
4					
5					

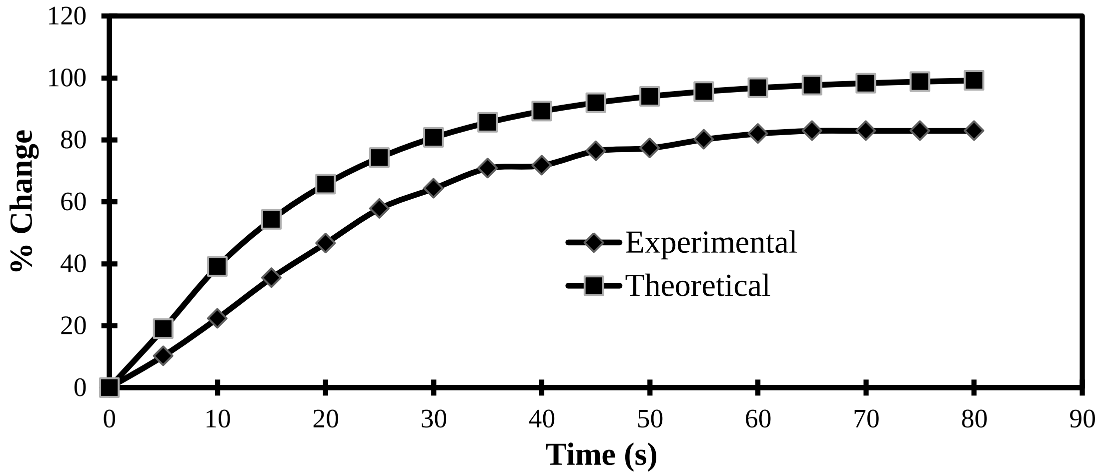


Figure 4 : Plot of theoretical and experimental step responses v/s time

Results:

The dynamics of the two tank, interacting system has been studied.

The theoretical and actual responses are compared for a step change in input and have been tabulated.

Inference:

STUDY OF VALVES

AIM: To study the On-off, Linear Percentage, Equal Percentage valves for a level process and to plot the response curve for a step change in set point.

APPARATUS: Experimental setup, stop watch.

THEORY:

Regulating valves are the most important actuating devices in engineering processes. All the valves are basically modelled with the same basic equation called the valve sizing equation given by:

$$q = C_v(l)\frac{\sqrt{\Delta P_v}}{\sqrt{\rho_f}}$$

Where,

$q =$ Liquid flow rate.

$C_v =$ Valve co-efficient which is a function of percent valve opening, also called as lift (*l*).

$\Delta P_v =$ Pressure drop across the valve.

$\rho_f =$ fluid density.

The co-efficient is defined such that it is the flow rate in gpm of water at a pressure drop of 1 psi across a given valve. The manufacturers provide the characteristic curves of the different valves which are plots between $\frac{Q}{Q_{\max}}$ and percent lift.

Here we study three general valves:

On-Off valve:

Here, most of the flow variation is introduced in the lower end of the lift and is used when we want to deliver large flow rate as quickly as possible. The exact shape of the fast opening valve is not defined in standards. Therefore, two valves one giving a 80% flow for a 50% lift and other 90% flow for 60% lift, may both be regarded as having a On-Off characteristic. It is a special case of proportional control. If the gain is made very high, the valve will move from one extreme position to the other when there is a slight variation in the set point. This sensitive action is called the on off action because either the valve is fully open or fully closed.

$$\frac{Q}{Q_{\max}} = l^{\frac{1}{\alpha}}, \text{ where } \alpha>0.$$

Linear percentage:

To regulate the flow rates, we prefer this valve. The flow through this valve is proportional to the valve opening or the lift at a constant differential pressure. A linear valve achieves this by having a linear relationship between the valve lift and the orifice pass area. The steady state gain of the valve will be a constant.

$$\frac{Q}{Q_{\max}} = l$$

Equal percentage:

This valve is also used when regulating the flow rates is required. The flow rate increases more gradually with the valve position. With some non linear process, their steady state gain may decrease with processing flow rate. If we implement an equal percentage valve in the control system, we can now keep the system characteristic in terms of the product of the gain of the process and the valve and we would not have to worry about retuning the controller as much when the flow rate changes. The valve plug is so shaped such that each increment in valve lift increases the flow rate by a certain percentage of the previous flow.

$\frac{Q}{Q_{\max}} = \mathrm{R}^{(l-1)}$ where R= rangeability parameter.

The performance of all these valves can be judged by transient response of the output to specific changes in the input.

PROCEDURE:

1. All the electrical circuits were connected.
2. The compressor was switched on and the air pressure was supplied more than 25 psi to the regulators and the air regulator output pressure was set to 20 psi.
3. The bypass valve and the process outlet valve for On-Off valve was kept completely open whereas of the other valves were completely closed.
4. By turning the knob, we set the lift to different positions like 25%. 50% till 100 % in forward and backward movement and measure the time for rise in water level in the tank for 10 mm.
5. We then calculate the volumetric flow rate and the maximum value of it.
6. We then plot $\frac{Q}{Q_{\max}}$ and percent lift and study the valve characteristic for both forward and backward movement and get a hysteresis curve.
7. The same procedure is followed for linear and equal percentage valves also.

OBSERVATION TABLE:

Table 4: Observation table for On-Off valve.

Sl No.	Percentage opening of the valve (%)	Time (s)	Height of water in the level tank (mm)
1	0		
2	25		
3	50		
4	75		
5	100		
6	75		
7	50		
8	25		

Table 5: Observation table for Linear Percentage Valve.

Sl No.	Percentage opening of the valve (%)	Time (s)	Height of water in the level tank (mm)
1	0		
2	25		
3	50		
4	75		
5	100		
6	75		
7	50		
8	25		

Table 6: Observation table for Equal Percentage valve

Sl No.	**Percentage opening of the valve (%)**	**Time (s)**	**Height of water in the level tank (mm)**
1	0		
2	25		
3	50		
4	75		
5	100		
6	75		
7	50		
8	25		

MODEL CALCULATIONS:

For Observation No:2 :-

ON-OFF VALVE:

Volumetric flow rate , $Q = \dfrac{h \times A}{t}$;

Where *h*= Height of water in the level tank = 20 mm

A= Area of the tank = 0.1 m^2.

t= Time taken by water for 20 mm rise in the level tank.

$Q_0 = 0$

$$Q_1 = \frac{(20 \times 10^{-3})(0.1) \times 3600}{98} = 0.07 m^3 / hr$$

Similarly $Q_4 = Q_{\max}$

So, $\dfrac{Q_1}{Q_{\max}} =$

LINEAR PERCENTAGE VALVE:

Volumetric flow rate , $Q = \dfrac{h \times A}{t}$;

Where *h*= Height of water in the level tank = 20 mm = 20×10^{-3} m.

A= Area of the tank = 0.1 m^2.

t= Time taken by water for 20 mm rise in the level tank.

$Q_0 = 0$

$$Q_1 = \frac{(20\times10^{-3})(0.1)\times3600}{85} = 0.0847 m^3/hr$$

Similarly $Q_4 = Q_{max}$ =0.1946 m^3/hr

So, $\frac{Q_1}{Q_{max}} =$

EQUAL PERCENTAGE VALVE:

Volumetric flow rate , $Q = \frac{h\times A}{t}$;

Where *h*= Height of water in the level tank = 20 mm = 20×10^{-3} m.

A= Area of the tank = 0.1 m^2.

t= Time taken by water for 20 mm rise in the level tank.

$Q_0 = 0$

$Q_1 =$

Similarly $Q_4 = Q_{max}$

So, $\frac{Q_1}{Q_{max}} =$

RESULT TABLE:

Table 7: Result table for On-Off controller

SL NO.	**Volumetric flow rate (m^3/hr),** Q	$\frac{Q}{Q_{max}}$
1		
2		
3		
4		
5		
6		
7		
8		

.

Table 8: Result table for Linear Percentage valve.

SL NO.	**Volumetric flow rate (m^3/hr),** Q	$\frac{Q}{Q_{max}}$
1		
2		
3		
4		
5		
6		
7		
8		

Table 9: Result table for Equal Percentaage valve.

SL NO.	**Volumetric flow rate (m^3/hr),** Q	$\frac{Q}{Q_{max}}$
1		
2		
3		
4		
5		
6		
7		
8		

GRAPHS:

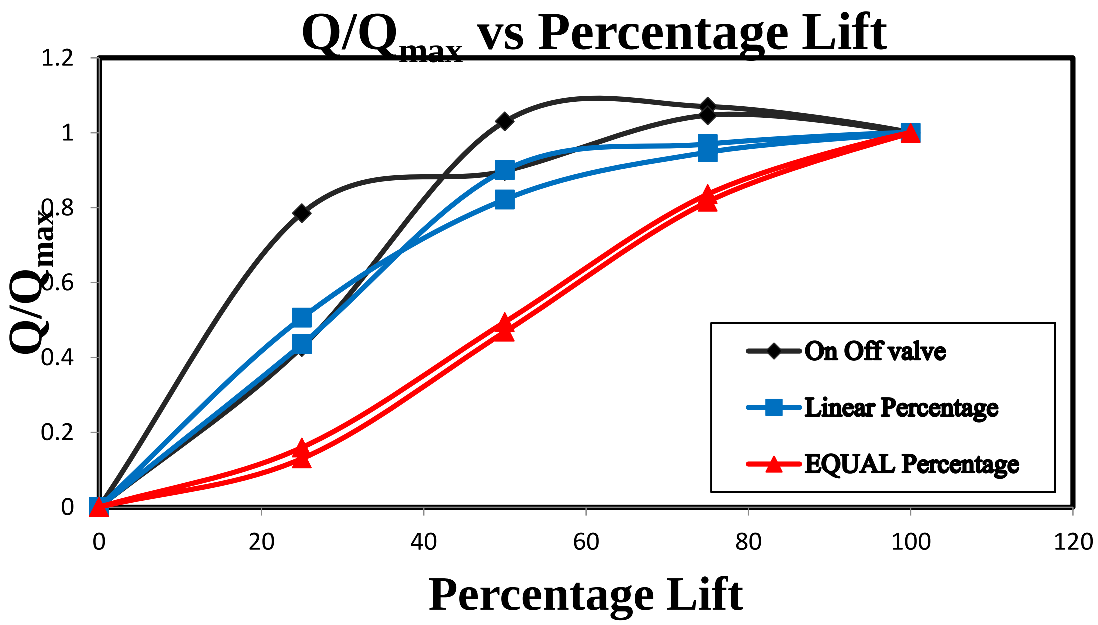


Figure 1: Q/Q_{max} versus % Opening of Valve

RESULT:

The On-off, Linear Percentage, Equal Percentage valves were studied and the response curve for step change in the set point was plotted for all the three valves.

INFERENCE:

STUDY OF CONTROL SYSTEMS

Aim:

To study the transient response of a liquid flow system for a step change in the set point using different controllers like Proportional (P), Proportional–Integral (PI), and Proportional–Integral–Derivative (PID) controllers respectively.

Apparatus:

Experimental Setup

Theory:

A control system is one that controls the value of the controlled variable for either a change in Set Point (Servo problem), a change in Load (Regulator problem), or a change in both. The comparator measures the error and the controller provides the necessary signal to actuate the final control element, which is usually a valve.

The simplest type of controller is the proportional controller. (The on/off control is actually the simplest, but it is a special case of the proportional controller). The proportional controller can reduce the error, but cannot eliminate it. If we can accept some residual error, proportional control may be the proper choice for the situation. The proportional Action may be represented as:

$$p = (K_c \times \varepsilon) + p_s \Rightarrow P(s)/\varepsilon(s) = K_c$$

$$1/K_c = P_b$$

Where, ε is the error and P_b is the bandwidth.

If any residual error cannot be tolerated, an additional control mode has to be introduced. If integral control is added to a proportional controller, the PI, or proportional–integral controller is obtained. The integral mode ultimately drives the error to zero. This controller has two adjustable parameters, the gain and the integral time. PI control is given by:

$$p = (K_c \times \varepsilon) + p_s + \left[\left(K_c/\tau_I\right) \times \int_0^t \varepsilon\, dt\right]$$

$$\Rightarrow P(s)/\varepsilon(s) = K_c\left(1 + \frac{1}{\tau_I s}\right)$$

Derivative control is another mode that can be added to our proportional or proportional–integral controllers. It acts upon the derivative of the error, so it is most active when the error is changingrapidly. It serves to reduce process oscillations.

The PID mode, however, is a combination of all the P and PI and PD modes of control. It is described by the relationship:

$$P(s)/\varepsilon(s) = K_c\left(1 + \frac{1}{\tau_I s} + \tau_D s\right)$$

Procedure:

1) All the electrical circuits are connected as shown and the compressor is switched on to build up the pressure.
2) The bypass valve and process outlet valve are kept half open.
3) The computer is switched on and the process control software is accessed.
4) The process parameters are entered such that the set point remains constant.
5) The time of logging into the software is set to a desired value and the bandwidth, integral value and derivative value are set for one of the values in the range in which the process is feasible (Range for P = 50 to 150, I = 20 to 80, D = 20 to 100).
6) The parameters are locked in as per the controller under study.
7) For P control, only the bandwidth is varied with integral and derivative values set at zero. For PI control, the bandwidth for which the least offset is obtained for the P control is noted and set constant, then the integral is varied. For PID control, the above process is done for both P and I values and then the derivative value is varied.
8) The process is started. The graph and the table for the given values of bandwidth, integral and derivative is noted.
9) The offset is then determined from the graph.

Observations:

Part 1: Proportional Control

Log Interval = 25 s and Set Value = 12 LPM

Table 1: Part 1 Observation Table

Sl. No.	Time (s)	Process Value for P = 50 (LPM)	Process Value for P = 100 (LPM)	Process Value for P = 180 (LPM)
1				
2				
3				
4				
5				
6				

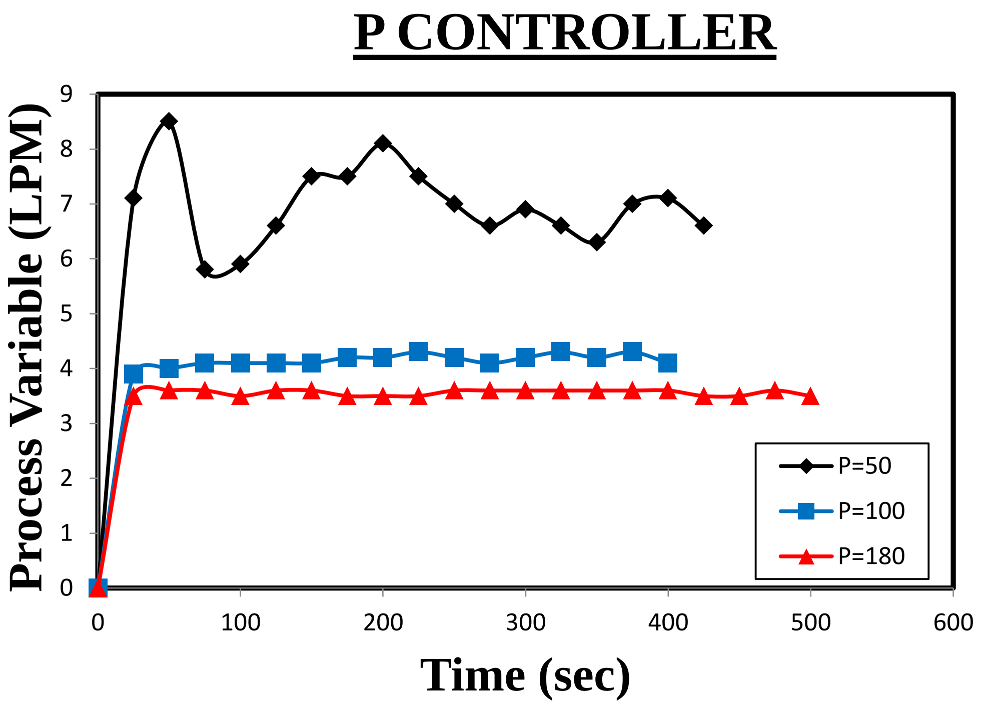


Figure 1: P Controller – Graph of Process Variable(LPM) vs Time(sec)

Table 2: Part 1 Result Table

Sl. No.	Bandwidth (P)	Process Value at Infinite Time	Offset
1	50		
2	100		
3	180		

Part 2: PI – Control

Bandwidth (P) = 50, Log Interval = 25 s, and Set Value = 12 LPM

Table 3: Part 2 Observation Table

Sl. No.	Time (s)	Process Value for I = 50 (LPM)	Process Value for I = 150 (LPM)	Process Value for I = 240 (LPM)
1				
2				
3				
4				
5				

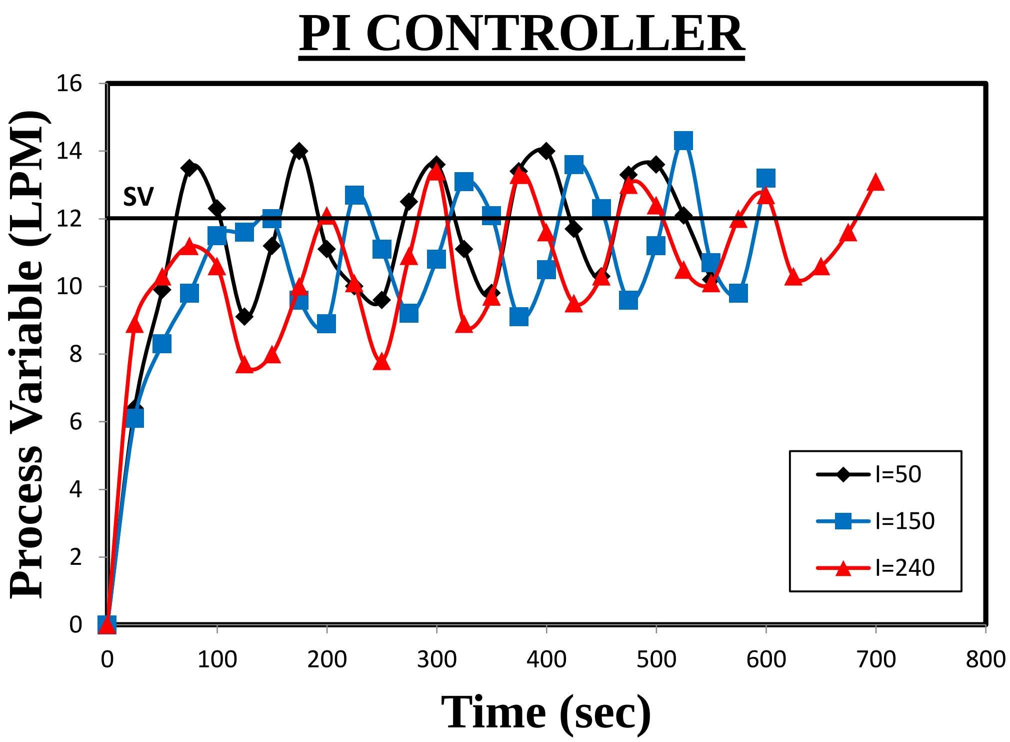


Figure 2: PI Controller – Graph of Process Variable(LPM) vs Time(sec)

Table 4: Part 2 Result Table

Sl. No.	Integral Value (I)	Process value at infinite time	Offset
1	50		
2	150		
3	240		

Part 3: PID – Control

Bandwidth (P) = 50, Integral (I) = 50, Log Interval = 25 s, and Set Value = 12 LPM

Table 5: Part 3 Observation Table

Sl. No.	Time (s)	Process Value for D = 30 (LPM)	Process Value for D = 50 (LPM)	Process Value for D = 300 (LPM)
1				
2				
3				
4				
5				

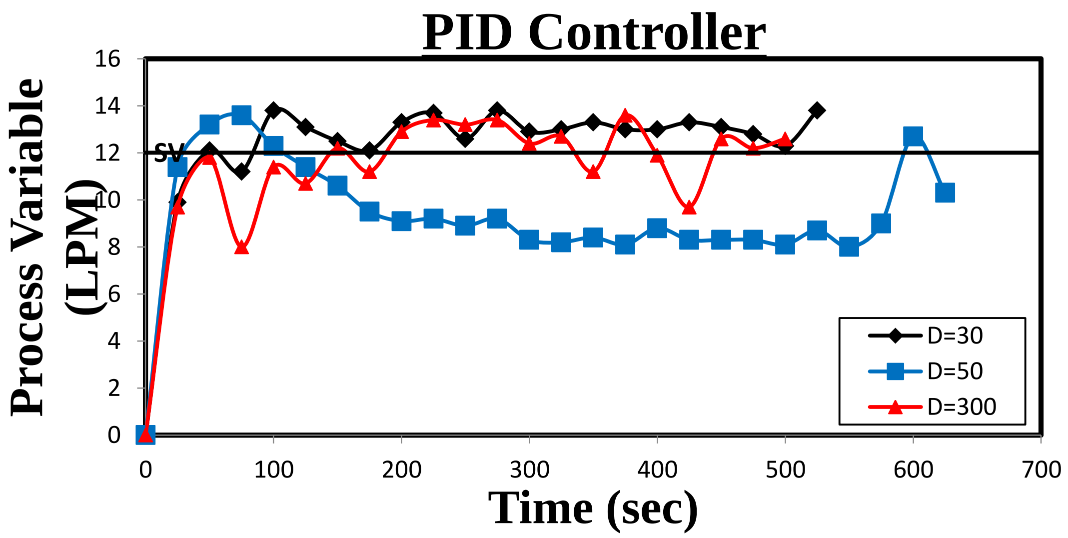


Figure 3: PID Controller – Graph of Process Variable(LPM) vs Time(sec)

Table 6: Result table for PID Control

Sl. No.	Derivative Value (D)	Process value at infinite time	Offset
1			
2			
3			

Result:

The transient response of the of a liquid flow system for step change in set point is determined using P, PI, and PID controllers and the values for offset is tabulated as shown above.

Inference: