DATE | Experiment 1 : Pressure Control Trainer | SHEET NO.

Aim

To find the parameter of the controllers in the pressure trainer

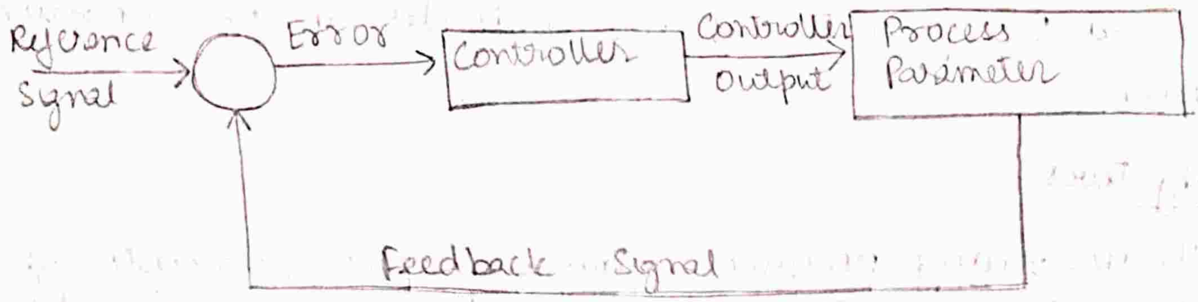
Objectives

- Understanding pressure control principles, concepts of set points, control algorithm, feedback loops and the interaction between various components in a pressure control system.
- Sensor - Actuator interaction - how the pressure transmitter continously senses the process variable and sends signal to the control module to adjust the actuator accordingly.
- Control Algorithm proportion, integral and derivative control algorithm and their role in maintaining a stable pressure level within the tank.
- The process parameter (pressure) is controlled through a computer.

Theory

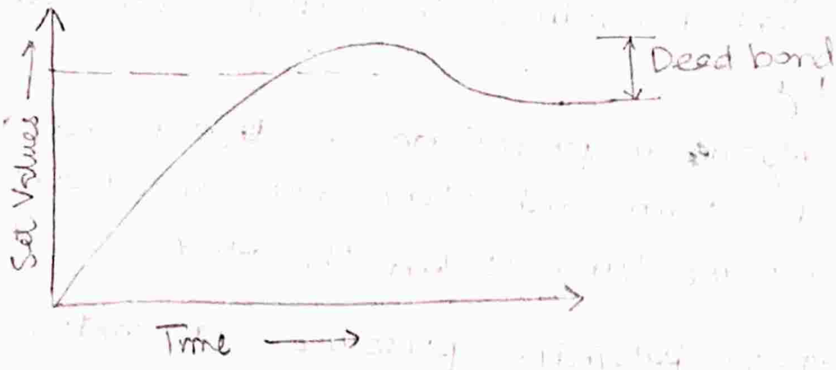
Process Controller : In an automatically controlled process, the parameter to be controlled is measured is measured and compared within the set point by the process controller. The difference between the measured signal and the setpoint is an error. The controller

Fig 1



Block diagram of Typical Controller

Fig 2



On-Off controller

performs online calculations based on error and other setting parameters and generates an output signal. The output signal drives the final control elements like a control valve or a damper to control the process to the set point.

Proportional (P) Controllers

- Generates a control output linearly proportional to the deviation between the setpoint and process variable.
- Helps regulate processes by adjusting the control output based on the error signal.
- The controller output (OP) is given by the formula

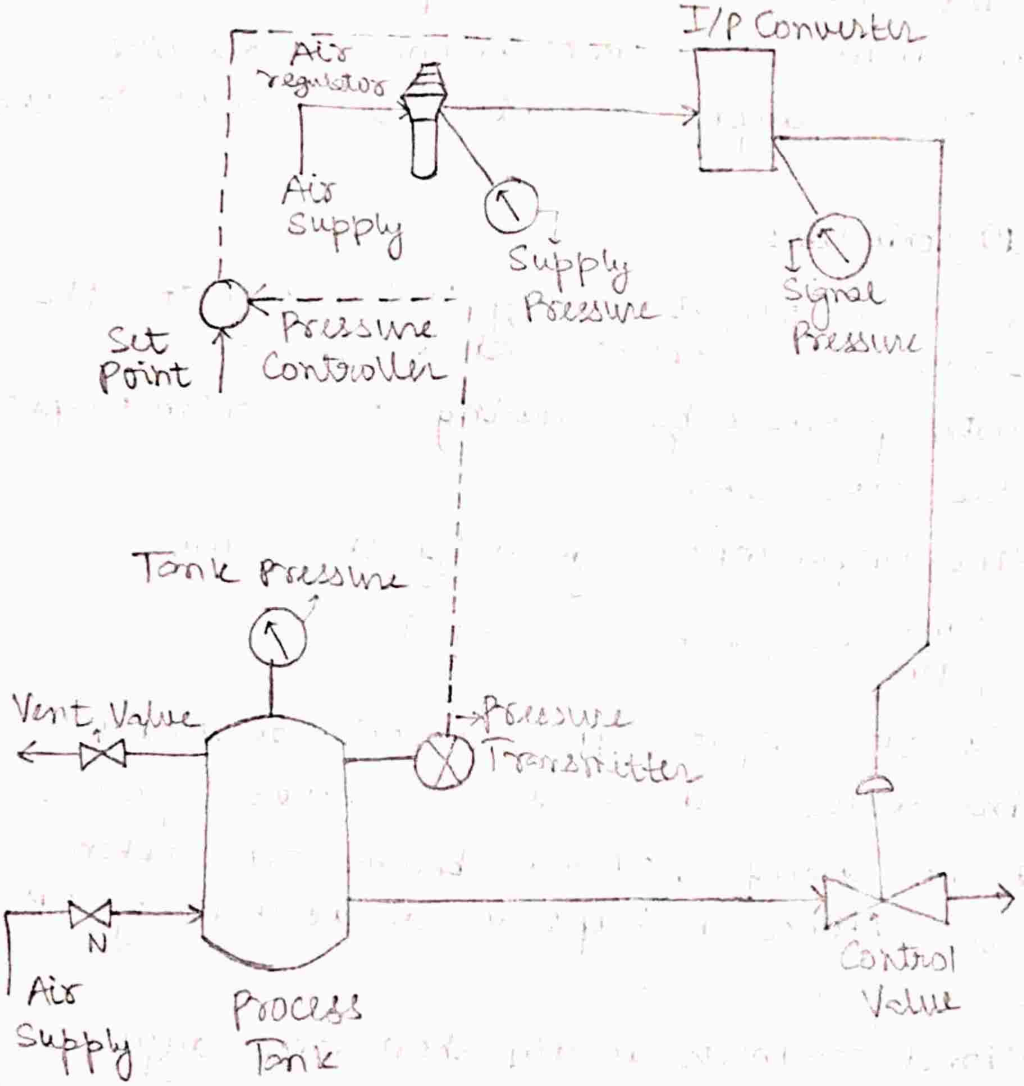
$$OP = \left[\frac{100}{PB} \times e\right] + b \quad \text{— eq 1}$$

where OP is the output, PB is proportional band in %, b is the bias value and e is the error signal.
If there is no biasing, OP will become zero when error is zero. Hence b helps to decide value of OP when error is zero.

- The proportional controller usually show some difference between the set point and process variable called offset. Offset can be reduced by decreasing PB or by readjusting the bias.

There are two types of controller actions -
(i) increase in which output increases as measurement

Fig 3



Schematic of Pressure Control Trainee

increases. (error e = measurement − set point)

(2) Decrease in which output decreases as measurement increases (error e = set point − measurement)

Proportional Derivative (PD) Controller

This mode of control is described by the relationship $OP = b + \frac{100}{PB}\left(e + T_d \frac{de}{dt}\right)$ where, OP is the output, e in error, T_d is derivative time. Larger the derivative time, larger is the action. Smaller in the proportional band, the larger is the derivative action. In order to achieve faster response and more stable operation in slow processes derivative action is added to apply an output component proportional to the rate of change of input (error)

Proportional - Integral - Derivative (PID) Controller

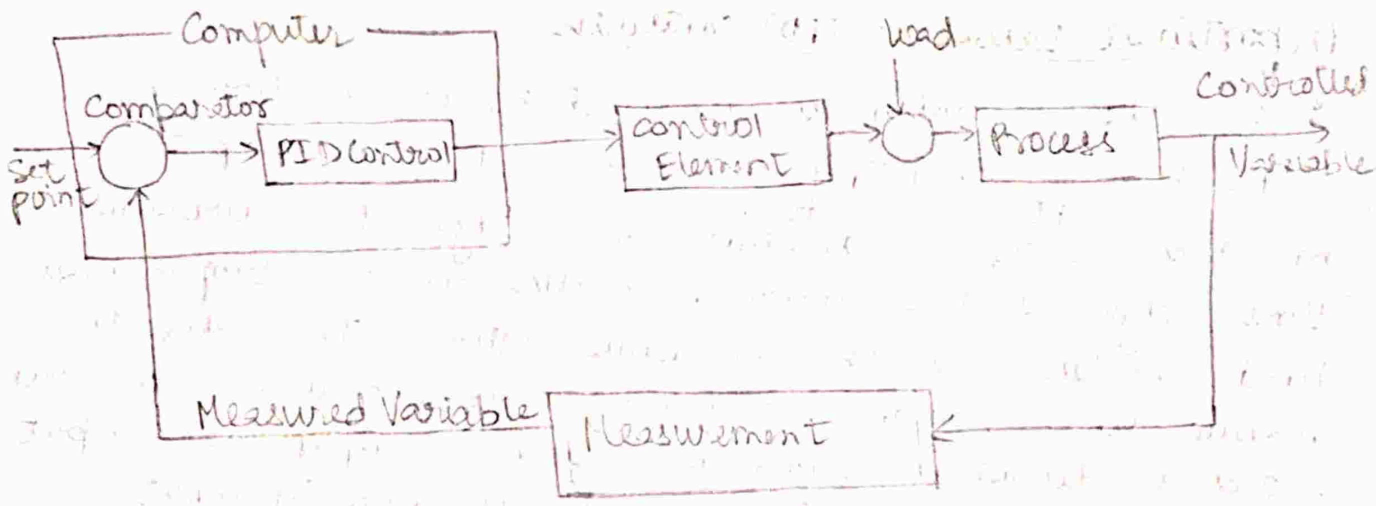
PID controllers are used for controlling almost all process variables like temperature, flow, level, pressure etc. In a continous or batch process. The output of a PID controller is given by

$$OP = b + \frac{100}{PB}\left(e + \frac{1}{T_I}\int e\,dt + T_d \frac{de}{dt}\right)$$

where T_I = integral time, T_d = derivative time.

Selection of proportional band, integral time and derivative time to achieve desired process response to load changes is called tuning of controller

Fig 4



Direct Digital Control (DDC)

Computer Control Techniques

Direct Digital Control (DDC)

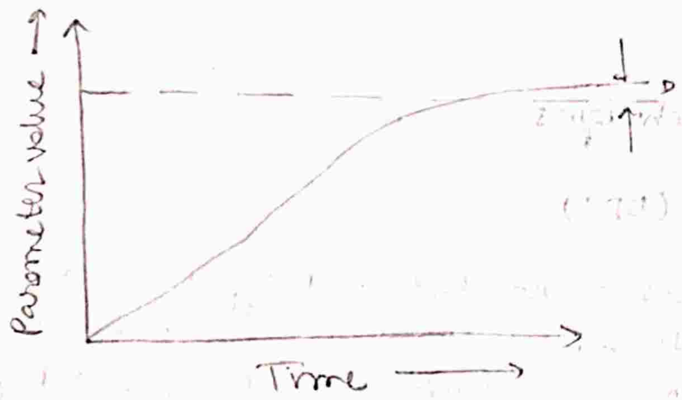
The method of process control described by the term DDC (Direct Digital Control) applies to those cases in which digital logic circuits or an computer are integral part of the loop. The software program defines all the control function, set point and deviation about the nominal. Direct Digital control has the capacity to control multivariable process with interaction b/w elements.

This is the most economically developed process system basically used for laboratory scale application. In this system the process signals are transmitted to computer through interfacing unit.

Supervisory Control and Data Acquisition (SCADA)

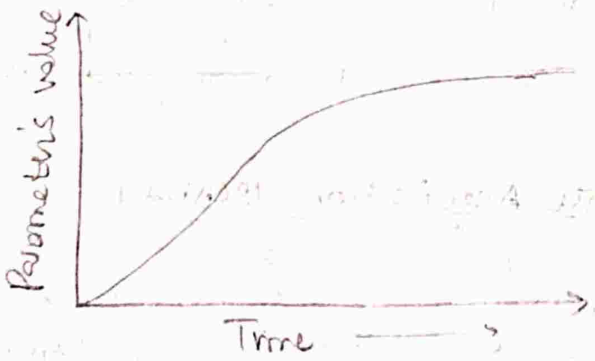
In SCADA system process signals are transmitted the local controller. The controller is in communication with central computer. The software performs the function of data acquisition display and analysis. The controller settings can be changed from computer. The computer has a supervisory role as controlling is done by local controller.
operates like a switch. These are simplest controller.
These controllers incorporate a dead band to keep the output from cycling rapidly b/w on & off. The controller will not turn on until the error signals move out of the dead band. Dark line and dotted line shows process parameter and reference values respectively.

Fig 5



Proportional (P) Controller

Fig 6



Proportional - Integral Controller

Procedures

① Study of open loop response

- start up the set, adjust the vent valve
- select open loop option from software
- close the control valve by increasing the controlling output to 100%
- apply the step change by 10% to controller output in manual mode, wait for process value to reach steady state value
- Repeat the above step until the controller output reaches to minimum 0%.

② Study of proportional controller

- select close loop option for control from software
- set the controller to proportional control (P) mode
- Adjust the process value by switching the controller to a particular pressure (say 50%) on the screen and apply output of the controller as bias value.
- Change the proportional band to 100%.
- Observe the effect of every low proportional band values

③ Study of proportional derivative controller

- start up the ~~set up and~~ select close loop option for control
- select PD controller, set the proportional band estimated from proportional control (P only). Set derivative time =0 and integral time = 6000s

- Set the set point to desired value. Allow the process to reach at steady state. Note the response of the system.

④ <u>Study of proportional integral derivative controller</u>

- Start up the set up, select close loop option for control from software.
- Select PID controller
- Switch the controller to manual mode.
- Change the proportional band to the value that estimated in proportional controller. Set integral time and derivative time based on the responses in previous experiments
- Adjust the set point to @ 50%. Switch the controller to auto mode. Apply step change of 10%.
- Observe the process response

Observation Table

Table No. 1

Open Loop

	Output %	PV (Process Variable) (psi)
	100	39.6
	90	39.4
	80	39.1
	70	38.6
	60	38.1
Bias Value	50	37.6
	40	36.9
	30	35.9
	20	34.9
	10	35.1
	0	35.1

- The median value of the PV comes out to be corresponding to 50% output i.e. 37.6
- The value of 37.6 will be chosen as the set point value for the closed loop analysis of P, PD, PID controllers

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P-Controller

Table No. 2

Kc	SP(psi)	PV(psi)	Offset(psi)
30	37.6	38.5	0.9
40	37.6	38.6	1
50	37.6	38.6	1
70	37.6	38.6	1
100	37.6	38.7	1.1

→ Minimum offset @ $K_c = 30$

P-D Controller

Table No. 3

@ $K_c = 30$

T_D(s)	SP(psi)	PV(psi)	Offset (psi)
5	37.6	38.5	0.9
10	37.6	38.5	0.9
20	37.6	38.5	0.9

- For $T_D > 20$, oscillatory movement, no steady state hence can't measure process variable
- Minimum offset @ $K_c = 30$ & $T_D = 20$

P.R.E.

PID Controller

Table No. 4

@ $K_C = 30$ and $T_D = 20$

T_i(1/s)	SP(psi)	PV(psi)	Offset(psi)
1	37.6	37.7	0.1
10	37.6	37.6	0
15	37.6	37.4	0.2
20	37.6	37.5	0.1

- Minimum offset @ $K_C = 30$, $T_D = 20$, $T_I = 10$

Result

PID controller is the most effective in eliminating offset, followed by PD controller.
P controller tends to have the most signifiant offset because it lacks integral and derivative actions to adress steady-state errors and anticipatory control
We got zero offset in PID Controller at values of

$K_C = 30$

$T_D = 20$

$T_I = 10$

Conclusion

The pressure trainers is a fascinating tool which gives a very flexible way to test dependencies of an input output relationship on control system. However, it by itself is not enough and human Intervention is necessary to find optimum control parameters to gain desired results through high speed of convergence, no offset on borderline oscillatory response. From this experiments, the graphs and results generated can be used to successfully derive quantities close to (or atleast) to the local optimum.

The median value from the open loop controller or the subsequent set point for P, PD, PID controller was found to be 37.6 psi.

The optimum value of K_c, τ_D and τ_I which yielded the minimum offset value compared to the set point (derived from open loop controller) come out to be $K_c = 30$, $\tau_D = 20$ and $\tau_I = 10$

fig7

Open Loop (Process Variable (psi) vs. Output (%))

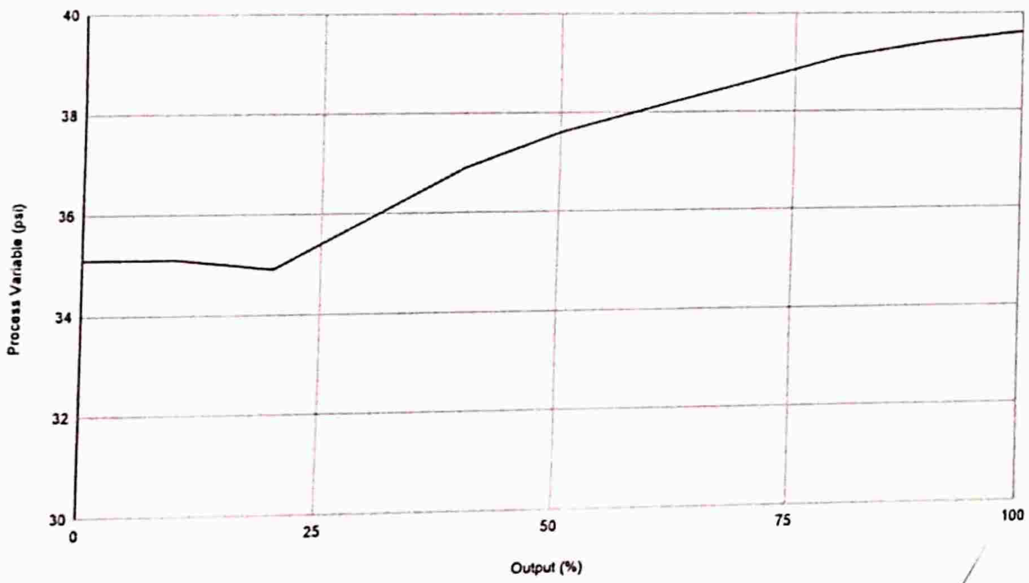


fig8

Process Variable (psi) vs. Derivative Time (Td)

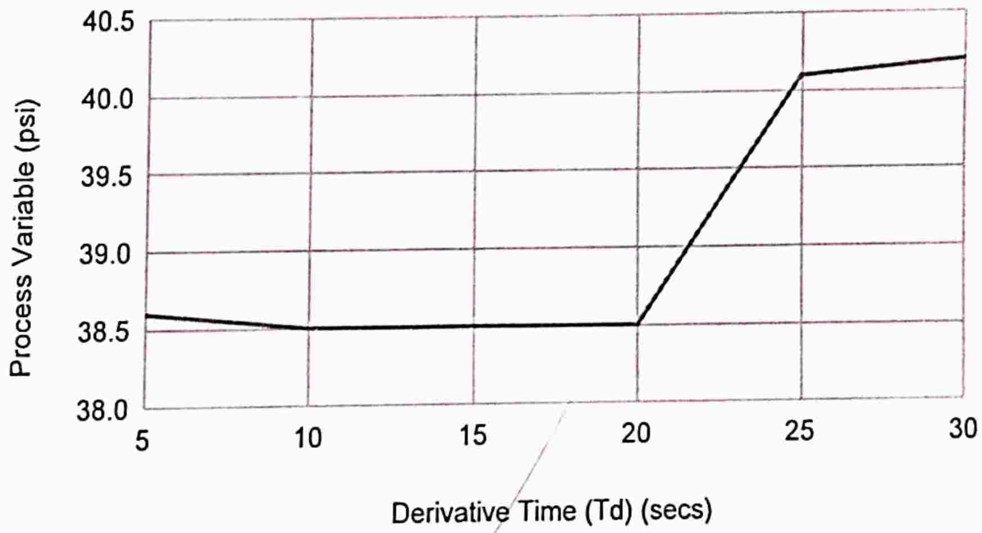
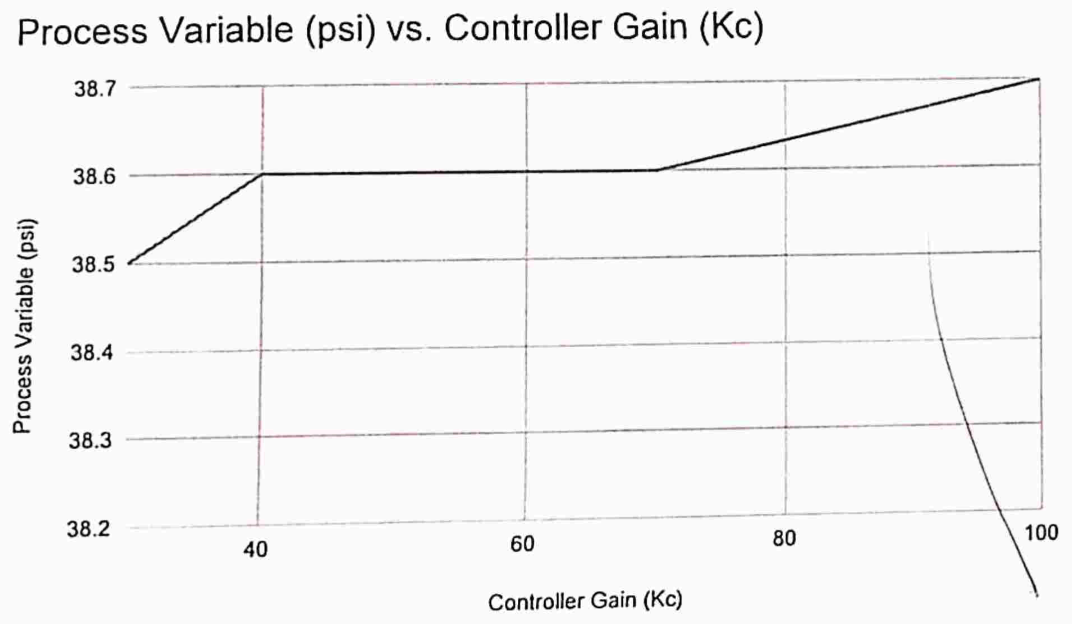
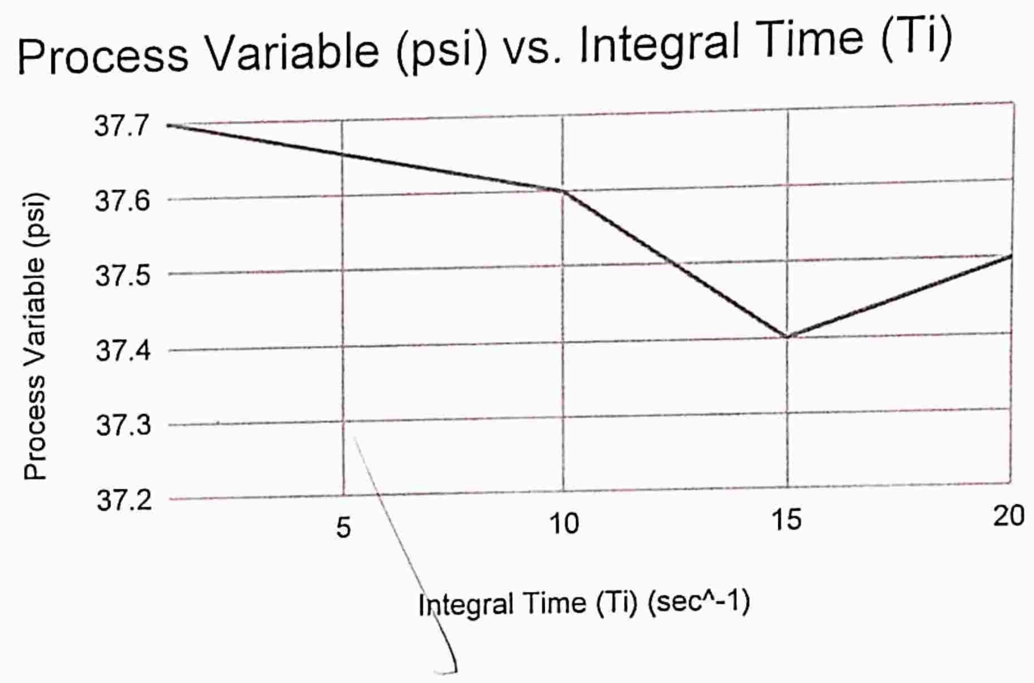


Fig 9



Process Variable (psi) vs. Controller Gain (Kc)
Process Variable (psi)
38.7
38.6
38.5
38.4
38.3
38.2
40
60
80
100
Controller Gain (Kc)

Fig 10



Process Variable (psi) vs. Integral Time (Ti)
Process Variable (psi)
37.7
37.6
37.5
37.4
37.3
37.2
5
10
15
20
Integral Time (Ti) (sec^-1)

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Discussion

① During the experiment, we observed that by adding an agressive response, the action of derivative controller added to improve the convergence speed. But on increasing it after 20, oscillatory motion dominates and hence not able to observe steady state. This could be speculation fueled by the external noise or can be attributed to the general equation of derivative control action.

② Open loop control system : Control system in which the output has an effect of independent of the system. It is economical to maintain and handy to use when output is difficult to measure. They can be inaccurate, unreliable and cannot automatically correct changes in the system.

③ Closed loop control system : Control system in which the output has an effect on the input quantity in such a manner that the input quantity will adjust itself based on the output generated. An open loop can be corrected into close loop by providing feedback. They are more accurate and reliable even in the presense of non-linearity. However they are costly and complicated.

④ The reading attains steady state after some time despite some changes in input, implying the latency involved in input output information/disturbance transfer and controller rate.

⑤ Some changes in the control parameters led to change in the last digits of the output, thus implying the importance of precision of the device.

⑥ Due to the divergence and undamped oscillation, occurring for control values of control parameter, the pressure vs time shows oscillatory behaviour

⑦ For all control scheme, the response corresponding to monotonic increase/decrease in parameters was not monotonic implying parameters to be finely tuned to achieve optimum value.

Precautions

① The readings of the process control variable showed some changes initially. Thus, the reading of the process variable should be only taken when it stablized / or attains a steady state value.

② Changes in some of the parameters can lead to false implication that process variable is not changing but it leads to change in last digit of process variable, which is not directly observable on the software.

③ No abrupt changes in the input parameters / control parameters should be done. The changes should be slowly and steadily and stepwise.

AIM

To tune the parameters of the controlled in the temperature control trainer.

OBJECTIVE

- To study the open loop response of a temperature control trainer.
- To study feedback proportional control (P control).
- To study steady state and transient response to a proportional + derivative control.
- To study steady state and transient response to a proportional + Integral + derivative controller.

THEORY

1. Study of Open loop Response

The feedback controlled variable is measured and compared with reference input and difference in signal to the control elements. If the main variable is not used to input adjust any of the input automatically system is an open loop control system.

PROCEDURE

- The set was started up and vent valve was adjusted.
- Select open loop action.
- Decrease control output to 0%.
- Start data logging on the computer.

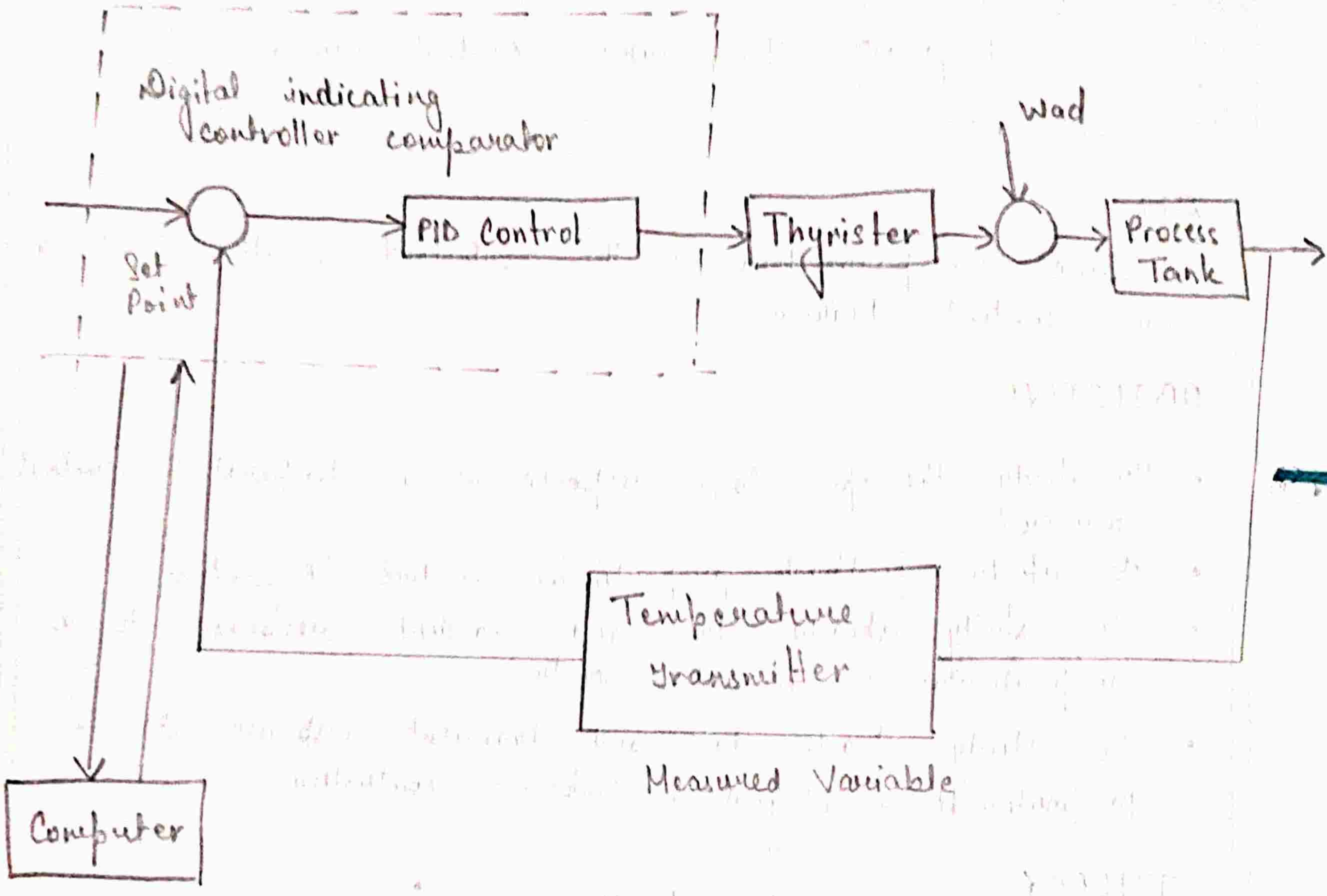

Fig. 1 Block Diagram of Temperature Control Trainer

- Apply the step change by 10% to controller output in manual mode, wait for temperature to reach steady state value.
- Repeat the above steps until the controller output reaches to maximum i.e 100%.

2. Study of Proportional Controller

THEORY: The control algorithm that generates a linear control output proportional to deviation is called proportional action. In proportional action the amount of change in measured value (or deviation) is expressed in percent of span that is required to cause the control output to change from 0 to 100% is called the proportional band.

The equation for proportional controller output is

$$p = K_p [SP - PV] + P_0$$

K_p = Proportional gain

P_0 = Bias [value of controller at 0 error]

PROCEDURE

- Setup is started and closed loop is selected.
- Controller is set to P mode.
- Process value is adjusted by changing controller to manual mode and output of controller is applied as bias. Proportional band is changed to 100%.

- Controller is switched back to auto.
- Set point is changed.
- Controller is switched to manual mode and different set is taken.

3. To study steady state and transient response to proportional + Integral control.

THEORY

Proportional Integral controller (PI)

$$e = SP - PV \qquad K_c = \left(\frac{1}{\text{Proportional band}}\right) \times 100$$

$$P = K_c e + \frac{K_c}{T_i} \int e\,dt + P_s$$

where T_i = Integral time
K_c = Proportional gain

PROCEDURE

- Start the set up and choose closed loop option.
- Adjust the process value by changing controller to manual mode to a particular temperature.
- Select PID controller. Set the set point to desired temperature. Start storing the data. Allow the process to reach steady state.
- Change the Integral time and apply step change to the set point by 2 to 3%.
- Switch on the controller to manual mode. Reduce the Integral time from half of the previous and repeat the above steps.

(iv) Study of Proportional Derivative controller.

THEORY

This mode of control is described by the relation

error, $e = SP - PV$

$$K_c = \frac{100}{\text{Proportional band}}$$

$$P = K_c e + K_c \tau_d \frac{de}{dt} + ps$$

τ_i = integral time

τ_d = derivative time

K_c = proportional gain

The derivative action generally used for slow processes. Larger the derivative time larger is the action. Smaller is the proportional band larger is the derivative action.

PROCEDURE

- Start the set up and choose closed loop option for control.
- Select PD controller set the proportional band estimated from proportional control (P only) and apply step change to the
- Change the derivative time and apply step change process.
- Increase the ~~process~~ derivative time and apply step change to the process.
- Using trial and error, select a set of proportional band and derivative time which gives satisfactory response to the step change in set point.

(V) Study of Proportional Integral Derivative (PID)

THEORY

This mode of control is described by the relationship

$$p = K_c \varepsilon + \frac{K_c}{T_i}\int \varepsilon\, dt + K_c \varepsilon\, rd \frac{d\varepsilon}{dt} + ps$$

where,

error, e = SP − PV

$$K_c = \frac{1}{\text{Proportional Band}} \times 100$$

where rd = derivative time

r_i = integral time.

K_c = proportional gain.

PROCEDURE

- Start up the set up and choose close loop option for control system.
- Select PID controller
- Switch the controller to manual mode.
- Change the proportional band to the value set estimated in proportional controller set Integral and derivative time on the responses in previous experiments.
- Adjust the set point to 50%. switch the controller to manual mode. Apply change of 10%. observe the process response.

In this system the process variable is the temperature of out flow stream from the process tank and the manipulated variable is the voltage supplied to the heater coil from thyristor.

OBSERVATION

Open loop

Process Variable	Controller Output (%)
32.8	0
34.5	10
37.2	20
40.7	30
43.9	40
47.2	50
51.0	60
57.1	70
62.3	80
66.5	90
70.0	100

Bias ← 47.2

- The median value of the PV comes out to be corresponding to 50 % output i.e 47.2
- The value of 47.2 will be chosen as the set point value for the closed loop analysis of P, PD, PID controllers.

At Q = 30 lph and output as 50%.

Time (sec)	Process Variable
0	47.9
10	51.2
20	51.5
30	51.9
40	52.1
50	52.3
60	52.4
70	52.6
80	52.7
90	52.5
100	
110	52.3
120	52.3

Calculation of controller parameters from graph?

P Controller

Kc	Set Point (psi)	Process Variable	Offset
10	47.2	53.4	6.2
20	47.2	53.0	5.8
30	47.2	53.3	6.1

Minimum offset @ Kc = 20

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PD Controller

τ_D	SP (psi)	PV (psi)	Offset
1	47.2	48.8	1.6
5	47.2	48.7	1.5
10	47.2	48.9	1.7

Minimum offset @ $K_c = 20$ and $\tau_D = 5$.

PID Controller

τ_I	SP (psi)	PV (psi)	Offset
1	47.2	48.1	0.9
10	47.2	53.9	6.7
50	47.2	47.2	0.[illegible]

Minimum offset @ $K_c = 20$, $\tau_D = 5$ and $\tau_i = 50$

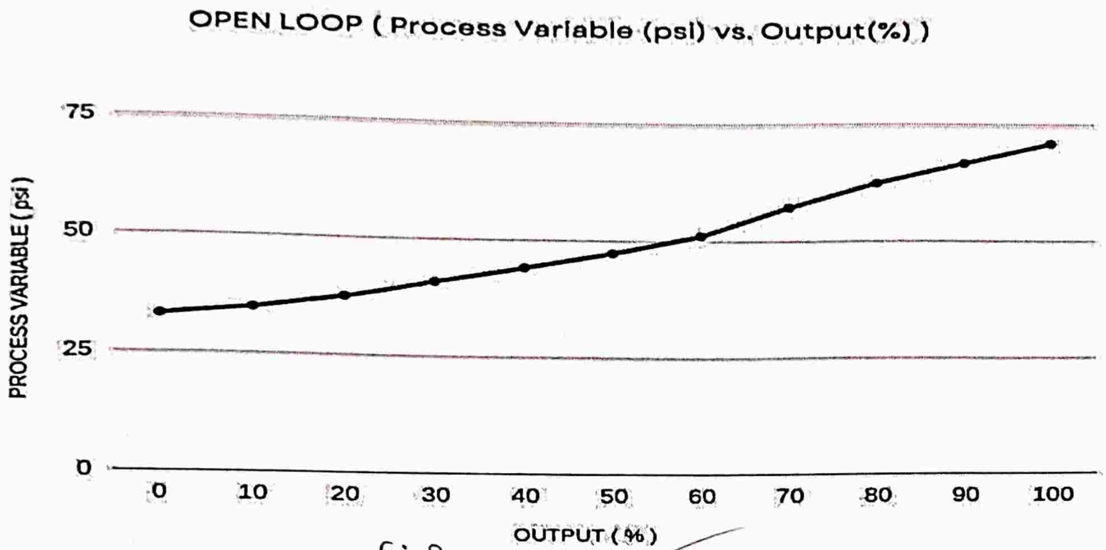

Fig2

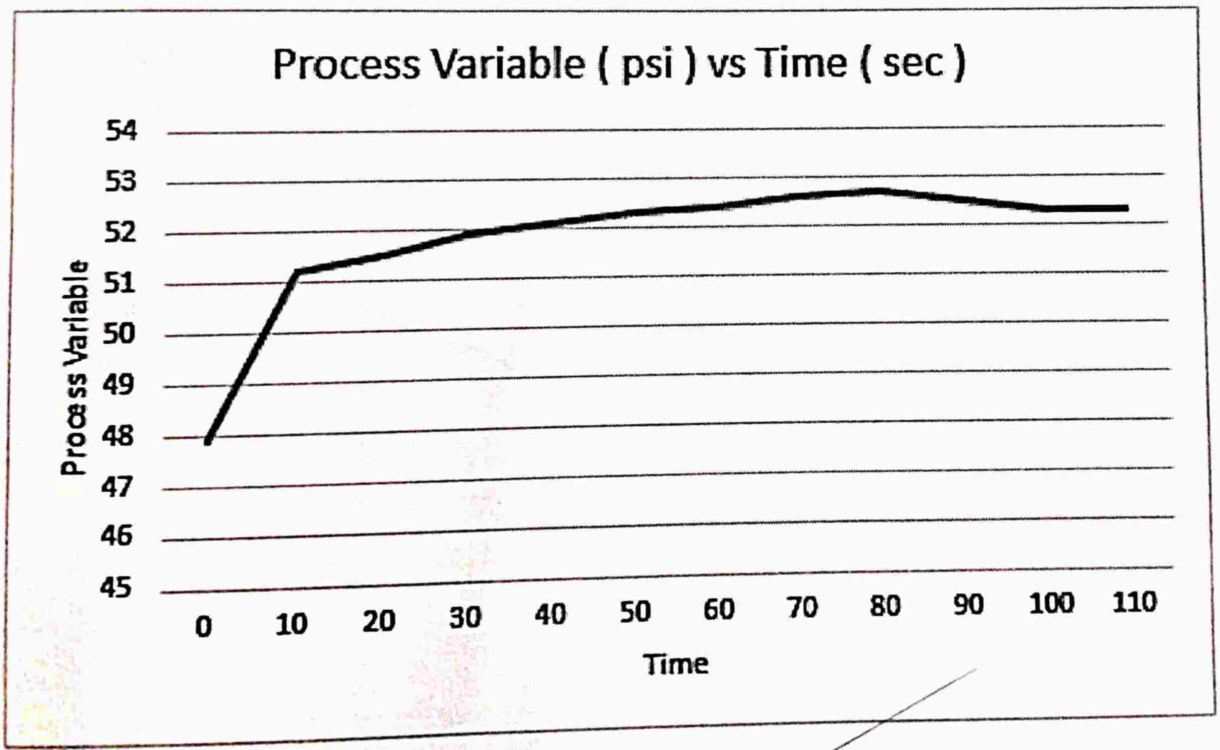

Fig3

write proper figure & captions

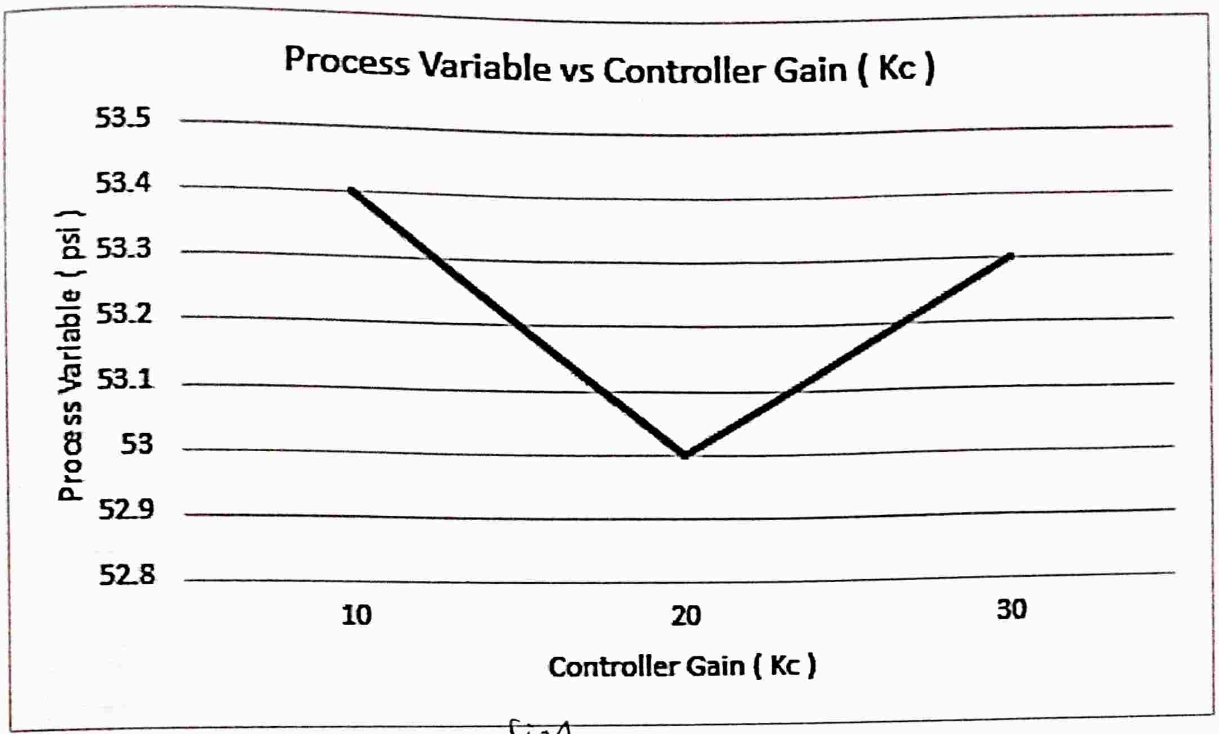
Process Variable vs Controller Gain (Kc)
Process Variable (psi)
53.5
53.4
53.3
53.2
53.1
53
52.9
52.8
10
20
30
Controller Gain (Kc)

fig4

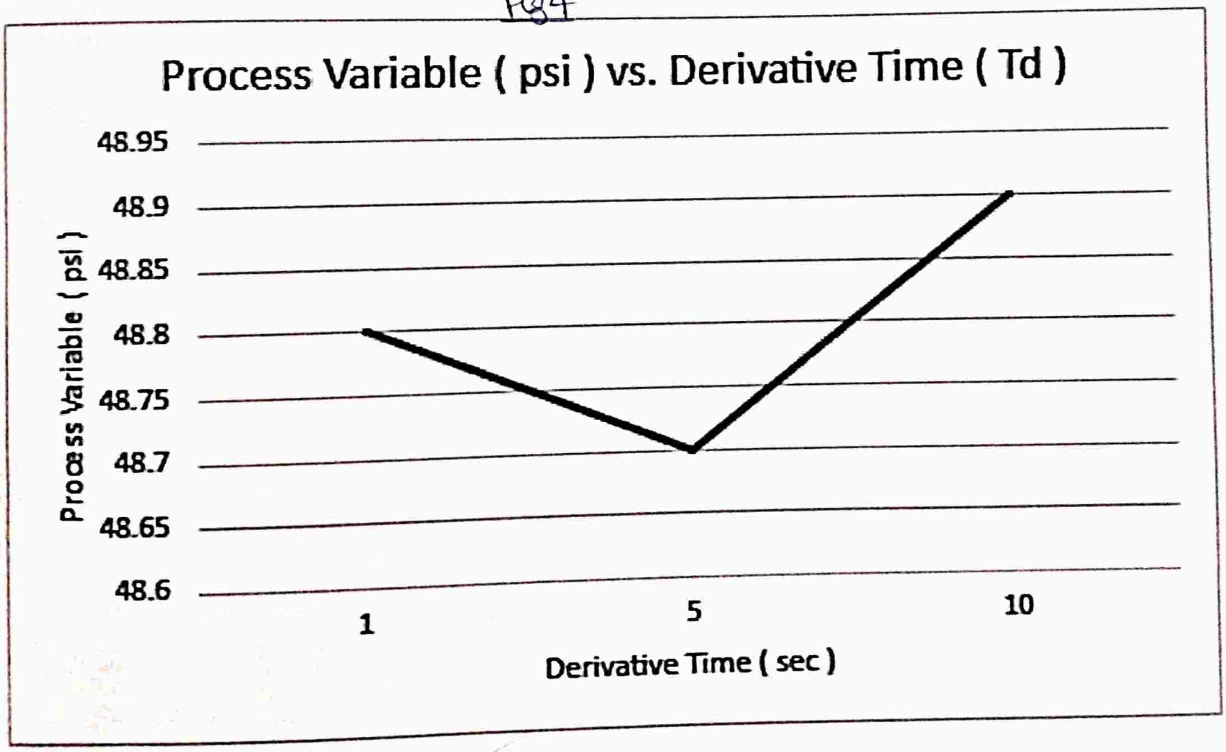
Process Variable (psi) vs. Derivative Time (Td)
Process Variable (psi)
48.95
48.9
48.85
48.8
48.75
48.7
48.65
48.6
1
5
10
Derivative Time (sec)

fig5

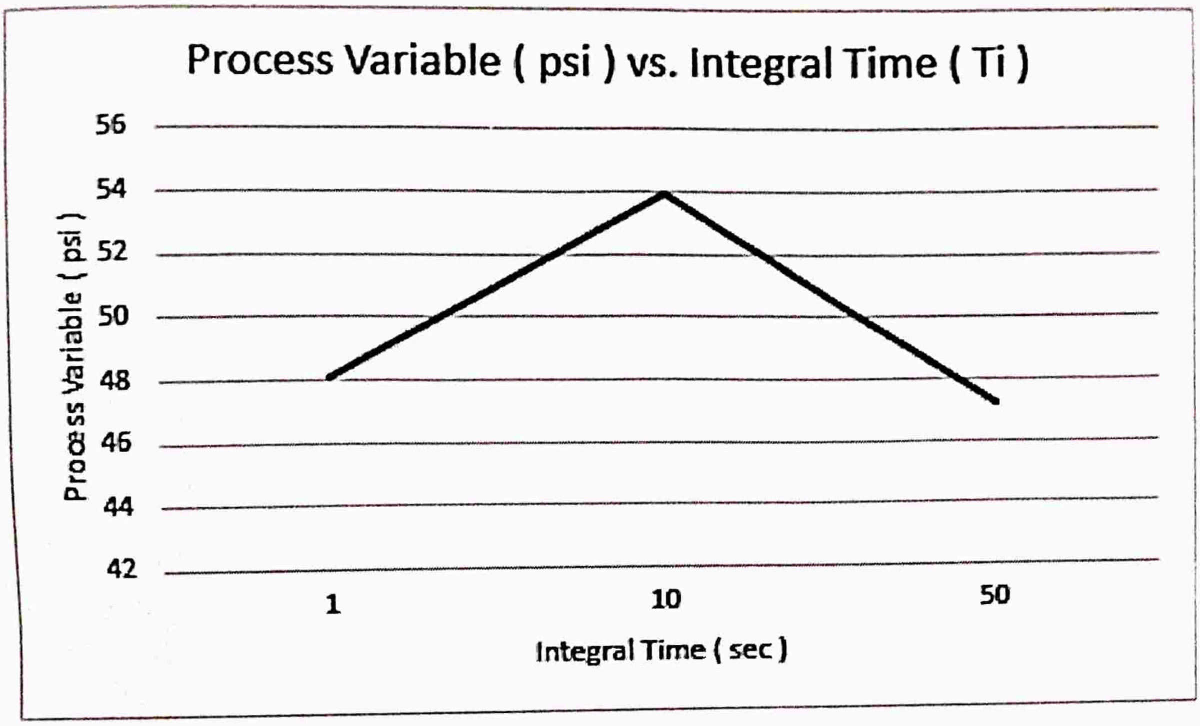
Process Variable (psi) vs. Integral Time (Ti)
Process Variable (psi)
56
54
52
50
48
46
44
42
1
10
50
Integral Time (sec)

Fig 6

RESULT AND CONCLUSION

PID controller is the most effective in eliminating offset, followed by PD controller.

P- only controller shows the most deviation since it lacks Integral and derivative actions to address steady state errors and anticipatory control.

DISCUSSION

In this experiment we used temperature control trainer for understanding the basic temperature control principle where water temperature was controlled and flow rate was fixed.

We used three different schemes i.e P, PI and PID for which the temperature responses were noted for ~~which~~ with time for variation in set points. we can see that

- In case of P only controller gain K_c determines the closeness the value of the control action towards set point.
- In case of PD controller, we used different P & I tuning parameters and it is clear from the graph that the offset to reduce by the derivative action.

- For PID we can clearly see from the graph that the oscillations increases as the value of D increases.

PRECAUTIONS

- The readings of the process control variable showed some changes initially. Thus, the readings of the process variable should only be taken when it stabilizes or attains steady state value.
- No abrupt changes in input variable / control parameters should be done. The changes should be slowly and steadily done.

DATE 14/10/23 | Exp-3 Temperature Measurement | SHEET NO.

Aim: To study the commonly used temperature sensors, calibrate them and evaluate their time constants.

Objective: Temperature measurement is the process of directly or indirectly measuring the instantaneous local temperature of a body or region for analysis or calculations. Many methods have been developed for measuring temperature. The most common device for measuring temperature is a mercury thermometer which will be used as a control for checking other devices. For our exp., we will be studying Thermocouple, Thermistor, RTDs, Bimetallic Thermometers. The resistance of the thermistor and RTD change with temperature which is used to estimate the temperature as we can measure the resistance.

1. CHARACTERISTICS OF RTD (PT 100)

Theory: RTD stands for Resistance Temperature Detector. RTDs are sometimes referred to generally as resistance thermometers. An RTD is a temperature sensor that mesures temperature using the principle that the resistance of the metal increases with increase in temperature of metal, measured in ohms (Ω).

Procedure:

- Keep the RTD probe and thermometer in the Ice bath.
- Connect the RTD output to multimeter to measure resistance in Ωhms.
- Increase temperature of Ice bath to @ 10°c by removing some ice and Adding water. Note readings of thermometer and multimeter.
- Repeat the above @ 20°c.
- Shift the RTD and thermometer from ice bath to hot water bath filled with water of ambient temperature and note reading.
- Switch on the heater of hot water bath for @ 30-40 second to raise the bath temperature to @ 40°c wait and note the reading.

repeat above step to get readings at the interval of @ 10°C

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2. Characteristics of Thermistor :

Theory: A Thermistor is a resistance thermometer or a resistor whose resistance is dependent on temperature. The term is a combination of "thermal" and "resistor". It is made of metallic oxides, pressed into a bead, disk or cylindrical shape and then encapsulated with epoxy or glass. Typically a thermistor achieves high precision within a limited temp. range of about 50°C around the target temperature.

Procedure:

Repeat the same procedure as explained for RTD, for thermistor. Note that the resistance of thermistor is in kOhms (kΩ).

3. Characteristics of Thermocouple :

Theory: A thermocouple is an electrical device consisting of two dissimilar electrical conductors forming an electrical junction. A thermocouple produces a temperature-dependent voltage as a result of the seeback effect, and this voltage can be interpreted to measure temperature.

a. <u>Bimetallic thermometer:</u>

A Bimetallic thermometer, converts the media's temperature into mechanical displacement using a bimetallic strip. Which consists of two different metals having different coefficients of thermal expansion. When the strip is heated, both metals expand to different extensions and the radius of curvature of the strip will change with temp.

<u>Procedure :</u> [Thermocouple]

Repeat the same procedure as explained for RTD, readings will be in mV and do note from Apparatus's voltmeter.

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Observations :

Calibration of Thermocouple, Thermistor & RTD

Table 1:

Temperature °C	Thermocouple mV	Thermistor KΩ	RTD Ω
0	0.03	28.58	101.1
10	0.09	18.6	107.7
20	0.15	12.58	109.2
30	0.24	10.41	114.2
40	0.35	8.38	119.2
50	0.84	4.14	122.1
60	1.23	3.41	125
70	1.51	2.62	127.7
80	1.93	1.92	130.3
90	2.24	1.67	131
100	2.67	1.25	135.5

Conclusion :

Thermocouple :

1. Thermocouple exhibit good linearty within their specified temperature range, making them suitable for a wide variety of temp. measurement applications.

P.R.E.

2. Aging effects can influence the accuracy of thermocouple over time, emphasizing the need for periodic recalibration to maintain measurement precision.

Thermistor :

1. Thermistors are highly sensible to temp. changes, making them ideal for applications requiring precision.

2. Thermistors can exhibit non-linearity, self-heating effects, and resistance changes with age, necessitating frequent recalibration to maintain accuracy.

RTD Sensor :

1. RTD sensors demonstrated remarkable accuracy and stability during the calibration process, making them a preffered choice for precise temp. measurements.

2. Callibration enabled the determination of the RTD's resistance - temperature relationship, typically described by the Callendar-Van Dusen equation.

fig 1.

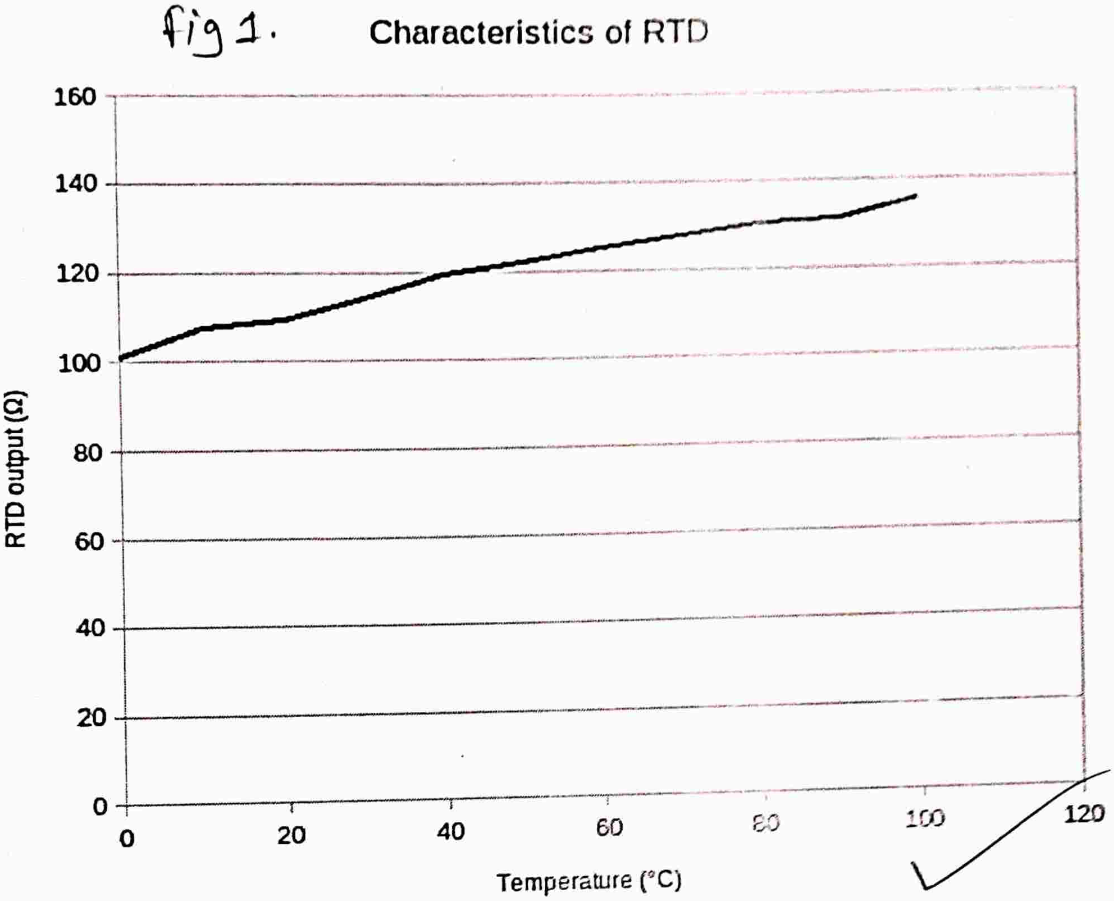

Characteristics of RTD
160
140
120
100
80
60
40
20
0
RTD output (Ω)
0
20
40
60
80
100
120
Temperature (°C)

fig 2.

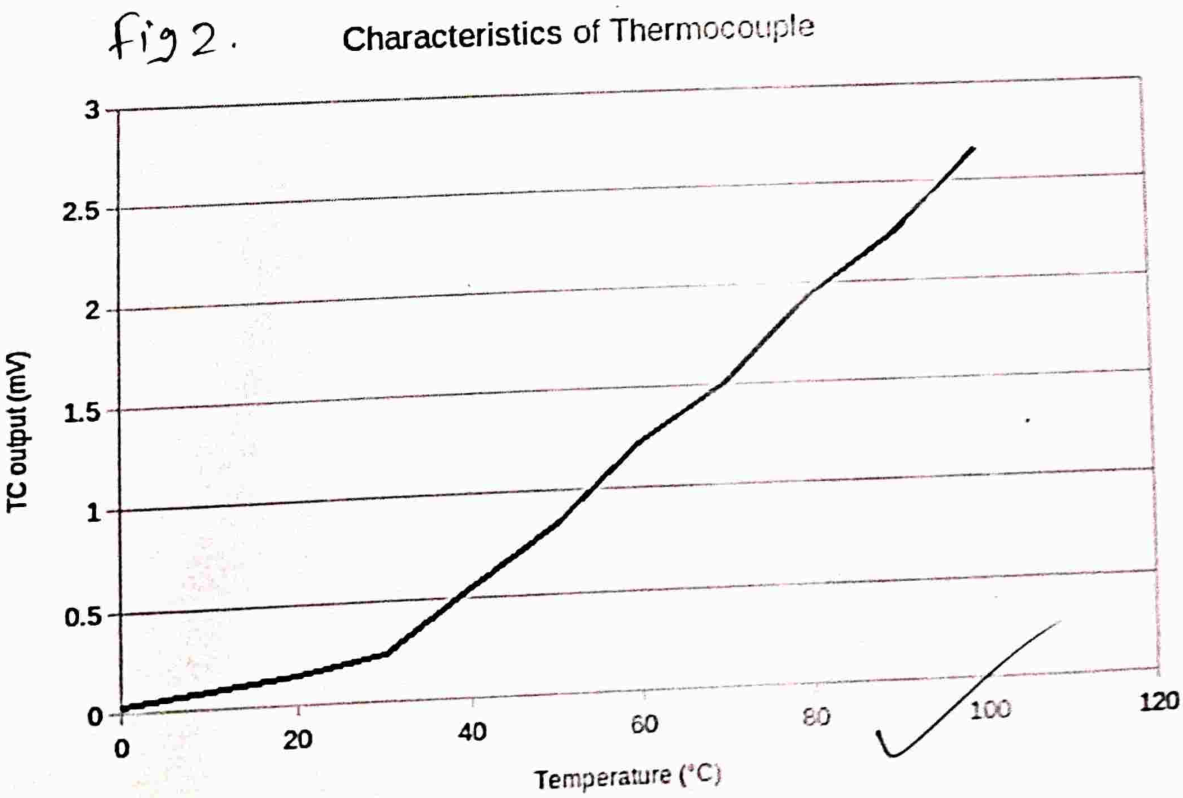
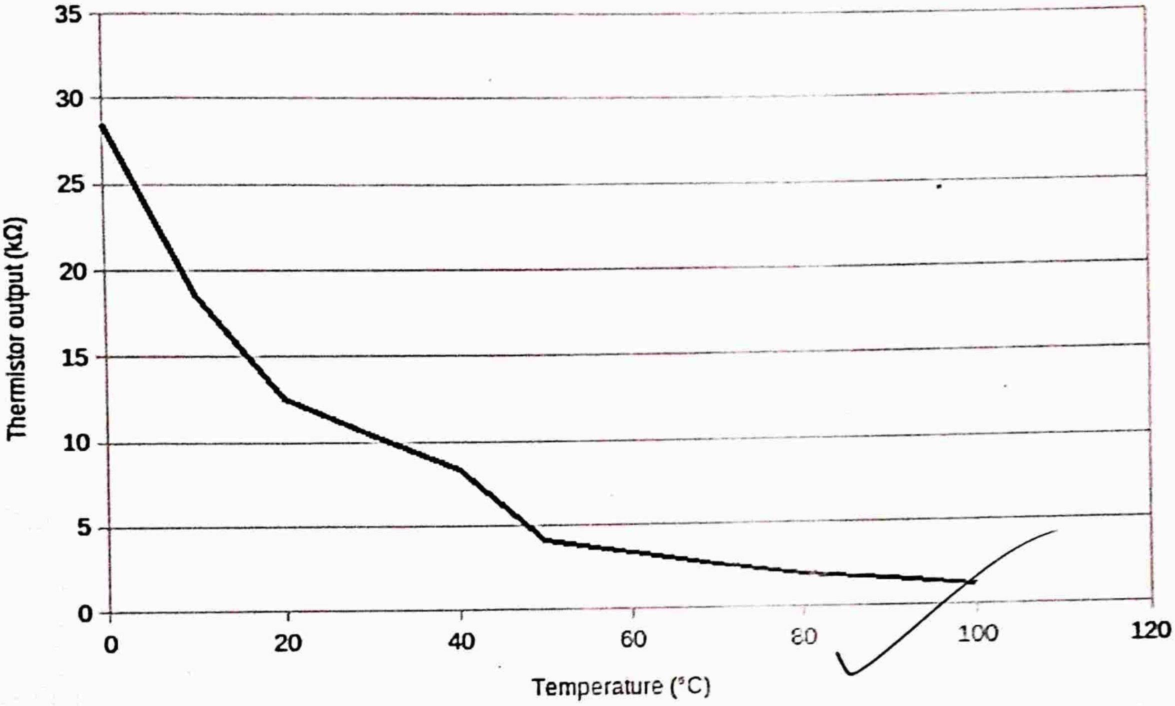

Characteristics of Thermocouple
3
2.5
2
1.5
1
0.5
0
TC output (mV)
0
20
40
60
80
100
120
Temperature (°C)

fig3. Characteristics of Thermistor



4. Time Constant of Mercury in Glass Thermometer

Procedure:
- Heat the water in hot water bath to 70-80°C
- Note the reading of mercury in glass thermometer.
- take out the thermometer when reaches steady state.
- Note down readings within interval of two 2 sec.

Observations: Table: 2

Time (sec)	Temperature (°C)
0	80
2	75
4	70
6	65
8	60
12	55
15	53
18	50
22	48
24	46
31	45
35	44
38	43
42	42
48	40
57	39

Time (sec)	Temperature (°C)
61	38
72	37
79	36
84	35
95	35
100	34
105	34
110	33.5
115	33
120	33
131	32.5
140	32.5
156	32.5
168	32
170	32

<u>calculation:</u> $T = T_0 e^{-t/\tau_p}$ @ $t = \tau_p$

$T = \frac{T_0}{e} = T_0 \times 0.368$

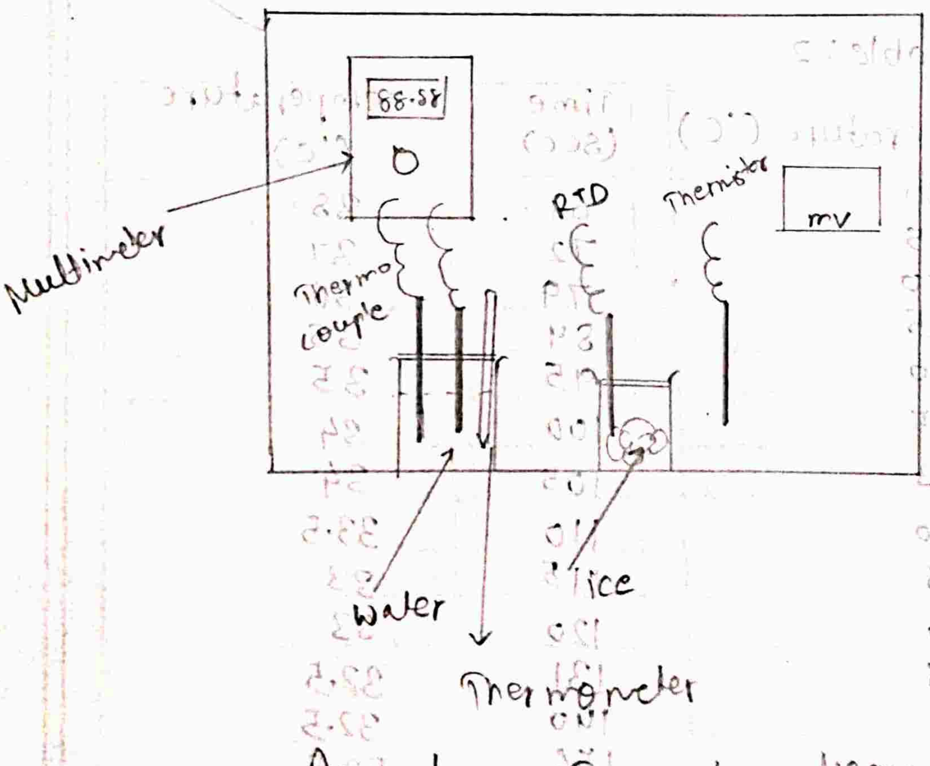
from graph →

$T = 32 + (80-32)\, 0.368 = 49.66\ ^\circ C$

$\therefore$ @ $t = \tau_p$ $T = 49.66\ ^\circ C$

$= 18.67$ sec

<u>Result:</u> time const. (τ_p) for Mercury in Glass-thermometer is 18.67 seconds.



Apparatus: Temperature Measurement.

5. Time Constant for Bimetal Thermometer

Procedure :

- Repeat the same procedure as explained for Mercury Glassthermometer.

Oberservations : Table : 3

Time (sec)	Temp. (°C)	Time (sec)	Temp. (°C)	Time (sec)	Temp. (°C)
0	85	46	64	102	53
2	84	48	64	106	52.5
4	83	50	63	109	52
6	82	53	62.5	113	51.5
8	81	54	62	115	50.5
10	80	56	61	120	50
12	78	58	61	122	49.5
14	77	60	60	127	49
16	76	62	60	130	48.5
18	75	64	59.5	134	48
20	74	66	59	138	47.5
22	73	68	58.5	143	47
24	72	70	58	145	46.5
26	71	72	58	148	46.5
28	70	74	57.5	150	46
30	69.5	77	57	153	45.5
32	69	80	56.5	156	45
34	68.5	84	56	160	44.5
36	68	87	55.5	166	44
38	67	90	55	170	43.5
40	66.5	93	54.5	174	43
42	66	95	54	177	42.5
44	65	98	53.5	180	42

Time (sec)	Temp (°C)
192	42.5
196	42
202	42
206	42
210	41.5
212	41
218	40.5

Time (sec)	Temp (°C)
224	40
232	39.5
238	39
243	39
248	39
255	38.5
263	38

Time (sec)	Temp (°C)
275	37.5
282	37
297	36.5
302	36
310	36
316	35.5
328	35
373	34.5

Calculation: $T = T_0 e^{-t/\tau_p}$

@ $t = \tau_p$ $T = 0.368\ T_0$

from graph: →

$T = 34.5 + 0.368\,(85 - 34.5) = 53.08\ ^\circ c$

@ $T = 53.08\ ^\circ c$ $t = 100$ sec.

Result: time const. for Bimetal thermometer is 100 sec.

fig 4. Mercury in Glass Thermometer

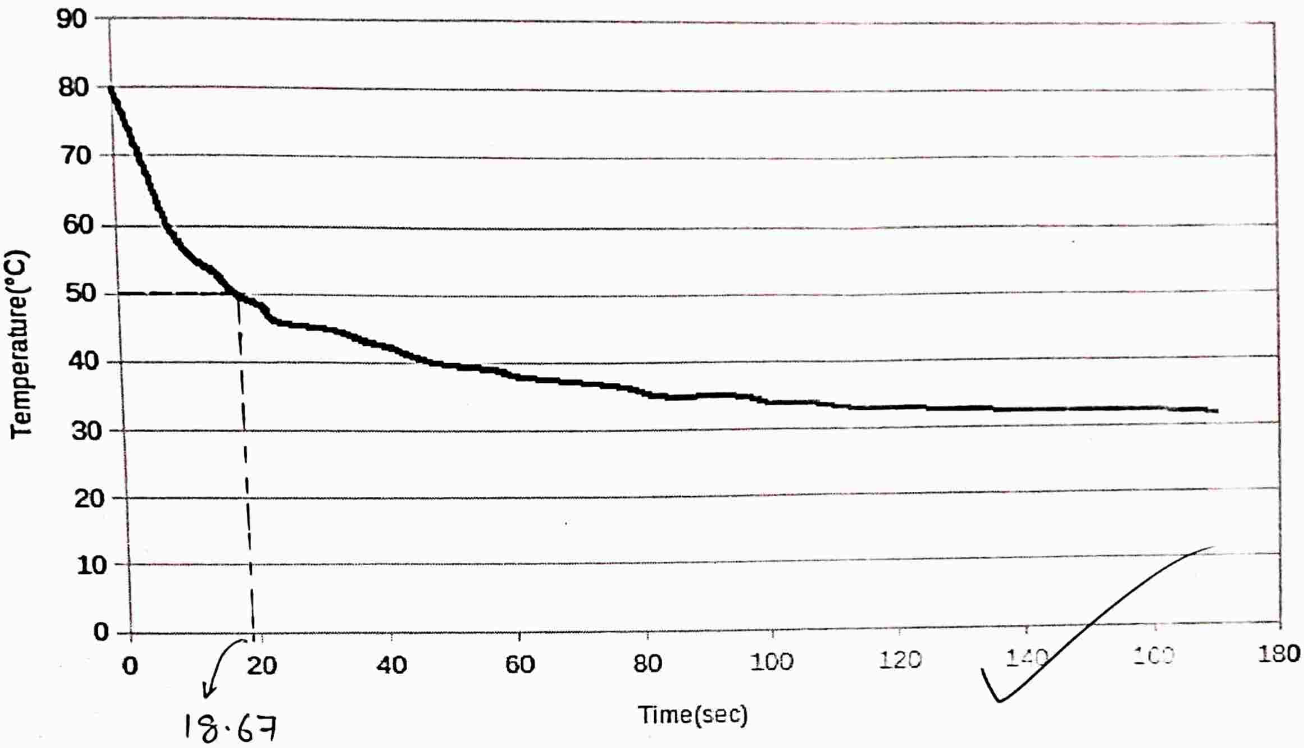
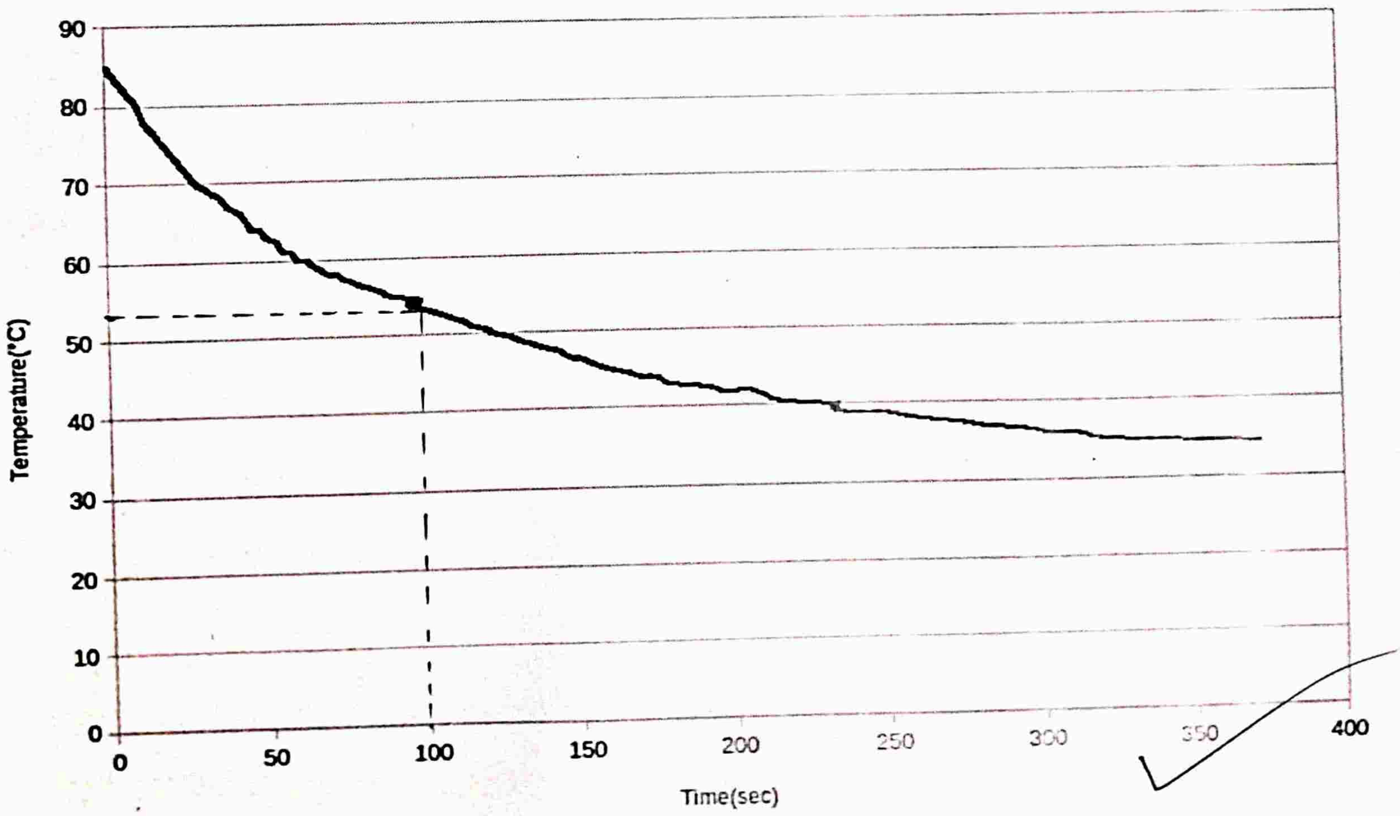


fig 5. Bimetal Thermometer



Discussion:

Calibration of sensors:

Calibration is essential for thermocouples, thermistor and RTDs to ensure accurate temperature measurements. This process involves comparing sensor outputs to known reference temperatures. The resulting calibration curves or equations establish the relationship between sensor readings and actual temperature.

Time constansts for thermometers:

The time constant for mercury glass and bimetal thermometers reveals their response time to temperature changes. for mercury glass it is 18.67 sec and for Bimetal it is 100 sec. Shorter time const. indicated faster response and longer time const. indicates slower response. It's crucial because of applications requiring rapid temperature monitoring or control.

——x——

~~FINISH~~

Precautions:

- check for compatibility between the thermocouple type and the temperature range of the experiment.
- Calibrate the thermistor before use to ensure accurate temp. measurement.
- clean pump regularly.

9/10

Rajdeep

——x——

FINISH

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DATE | Experiment : 4 | SHEET NO.

Objective : To study step response of a single capacity system, first order systems arranged in interacting and non interacting modes and impulse responses of first order system arranged in interacting and non interacting modes.

Theory : Single system generally makes use of only one beaker with constant source of water filling it in such a way that there is inlet and as well as outlet. The observed step responses ~~of~~ after inlet and outlet streams follow the first order equation. The equation is of the form

$$H(t) = AR\left(1 - e^{-t/\tau}\right) \Rightarrow H(s) = \frac{A}{s}\left\{\frac{R}{\tau s + 1}\right\}$$

for systems arranged in non interacting mode, equation is :

$$H_2(s) = AR_2\left[\frac{1}{s(\tau_1 s + 1)(\tau_2 s + 1)}\right]$$

for strictly impulsive response in 1st order system :

$$H_2(s) = \frac{VR_2}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

P.R.E.

Step response of first order system arranged in interacting mode has equation :-

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

Impulse response of first order systems arranged in interacting mode :-

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

Procedure :- (i) start the setup

(ii) Switch on the valve controlling the water input.

(iii) Allow the water to flow into the glass beakers.

(iv) For single capacity system, switch on the inlet of the upper single beaker only and also keep the outlet on. After the steady state is reached, note down the level at the steady state.

(v) After the steady state reaches, for each kind of system, for inter during step input, increase the water level by 10cm.

(vi) Now, keep on noticing the water level at the interval of every 15 seconds until the level again reaches the steady state.

(vii) For interacting systems, allow the water from beaker 1 to flow to beaker 2 and beaker 2 should be taken as outlet.

(viii) The same process used in the single beaker system should be repeated and for step input again, 10Lph increment should be done.

(ix) For non interacting system, water should be allowed to flow from beaker 2 to beaker 3 kept at the same level till the steady state is reached and again the step input in the form of 10LPH change in flowrate of rotameter should be introduced.

(x) Again, the steady state height should be noted after measuring heights at 15 sec intervals.

(xi) For impulse change, the input should be through the pump and outlet should be kept open and the steady state height should be measured.

(xii) After this, 150ml water is poured from the beaker to the glass tank and then again, the change in height is measured after the interval of 15 seconds.

(xiii) Then, a table is plotted to observe the value of heights and to compare them with the mathematically calculated heights.

Observations :

Single system. $\Delta f = 10$ Lph

Initial flowrate = 50 Lph

After 1st stepchange flowrate = 60 Lph.

Sr. NO.	Time (sec.)	level H(t) ~~Observed~~	H(t) observed	Steady Level (mm)	H(predicted)
1)	0	80	0	80	0
2)	10	85	5	80	9.568
3)	20	90	10	80	18.322
4)	30	101	21	80	26.331
5)	40	108	28	80	33.658
6)	50	110	30	80	40.362
7)	60	112	32	80	46.496
8)	70	114	34	80	52.107
9)	80	116	36	80	57.241
10)	90	117	37	80	61.939
11)	100	118	38	80	66.236
12)	110	119	39	80	70.168
13)	120	121	41	80	73.765
14)	130	122	42	80	77.056
15)	140	123	43	80	80.067
16)	150	124	44	80	82.822
17)	160	125	45	80	85.342
18)	170	126	46	80	87.648
19)	180	127	47	80	89.758
20)	190	127	47	80	91.688
21)	200	128	48	80	93.454

DATE | SHEET NO.

Non Interacting system

$f_P = 60$ Lph
$f_f = 70$ Lph.

Sr. No.	Time	Level (observed)	(cm)	Level (mm)	H (Pred)
1)	0	33	0	33	0
2)	10	34	1	33	0.105
3)	20	36	3	33	0.346
4)	30	38	5	33	1.06
5)	40	38	5	33	1.83
6)	50	38	5	33	2.67
7)	60	38	5	33	3.408
8)	70	38	5	33	4.27
9)	80	38	5	33	4.47
10)	90	38	5	33	5.396
11)	100	38	5	33	5.957
12)	110	38	5	33	6.470
13)	120	38	5	33	6.935
14)	130	38	5	33	7.36
15)	140	38	5	33	7.76
16)	150	40	7	33	8.721
17)	160	40	7	33	8.290
18)	170	42	9	33	8.746
19)	180	43	10	33	9.083
20)	190	44	11	33	9.275
21)	200	44	11	33	9.504
					9.708

Interacting system

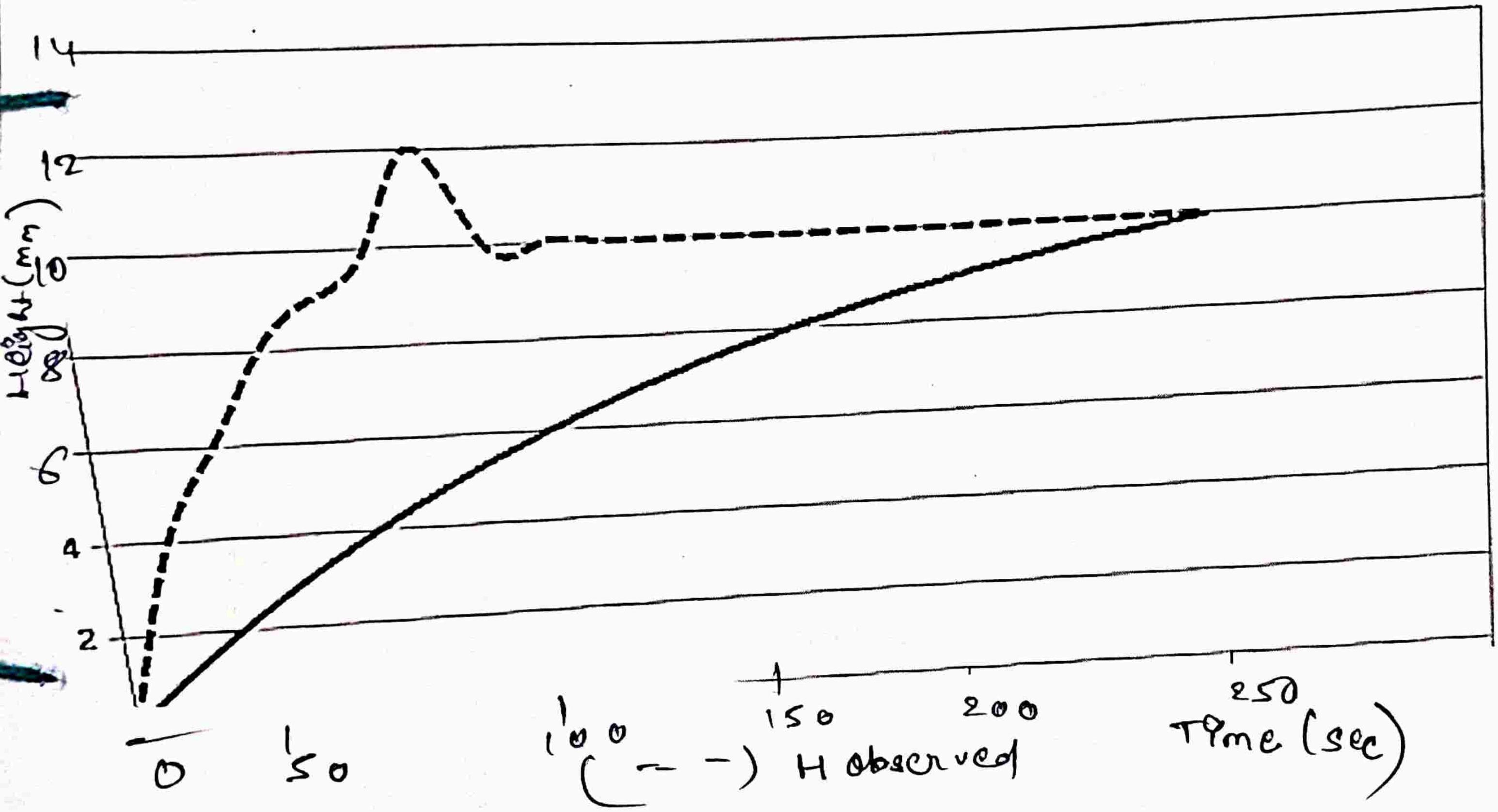
$f_i = 70\,LPh$

$f_f = 80\,LPh$

Sr. NO.	Time	Level ~~H (Observed)~~	H(obs)	Level (mm)	H (predicted)
1)	0	52	0	52	0
2)	10	56	4	52	0.732
3)	20	57	5	52	2.375
4)	30	58	6	52	4.409
5)	40	59	7	52	6.565
6)	50	60	8	52	8.703
7)	60	62	10	52	10.759
8)	70	63	11	52	12.701
9)	80	64	12	52	14.519
10)	90	66	14	52	16.21
11)	100	67	15	52	17.785
12)	110	68	16	52	19.242
13)	120	69	17	52	20.592
14)	130	70	18	52	21.842
15)	140	71	19	52	23.001
16)	150	72	20	52	24.072
17)	160	73	21	52	25.060
18)	170	74	22	52	25.975
19)	180	75	23	52	26.824
20)	190	75	23	52	27.604
21)	200	76.	24	52	28.329

graph should be professional.

Impulsive input in Single Capacity



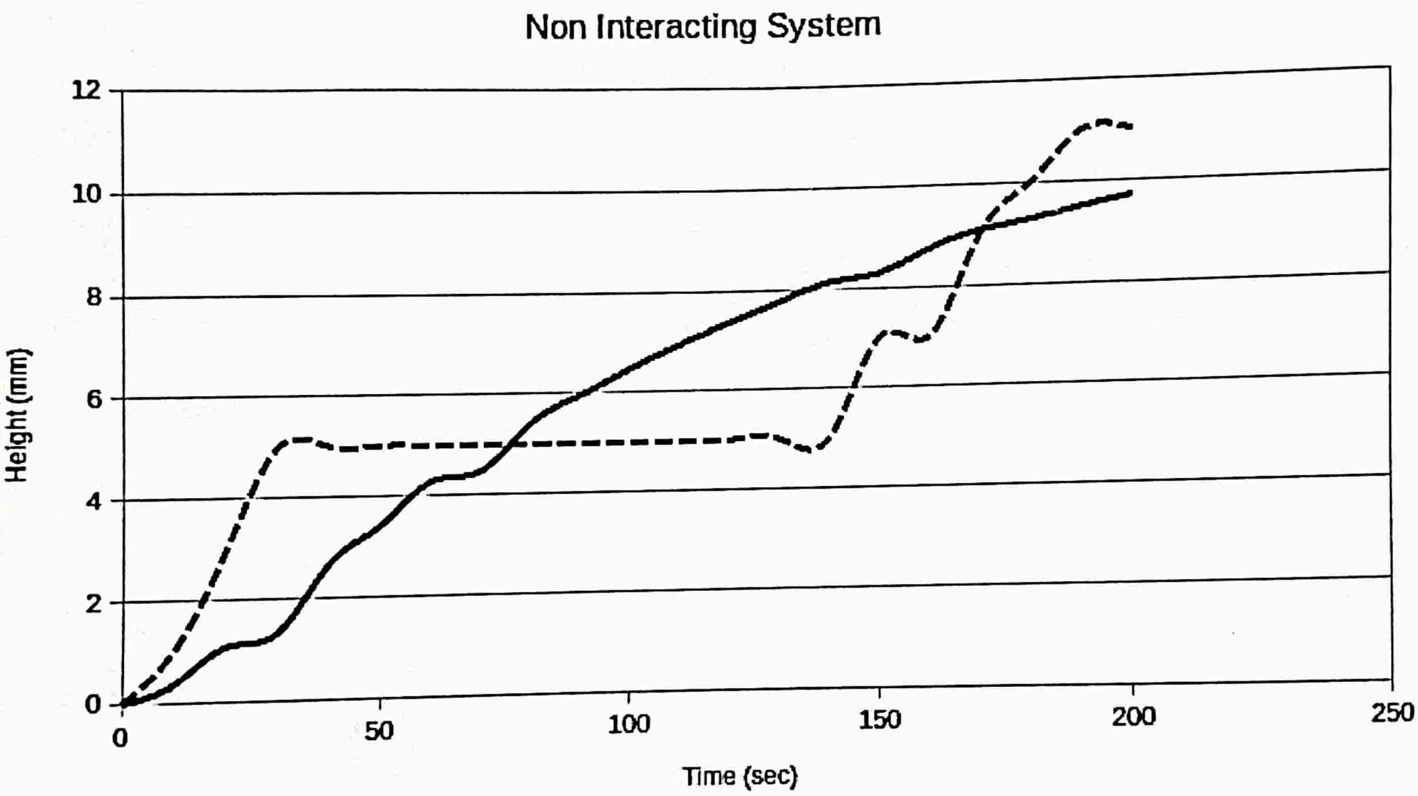
(- - -) H observed

(—) H pred.

Graph 1

fig-1;

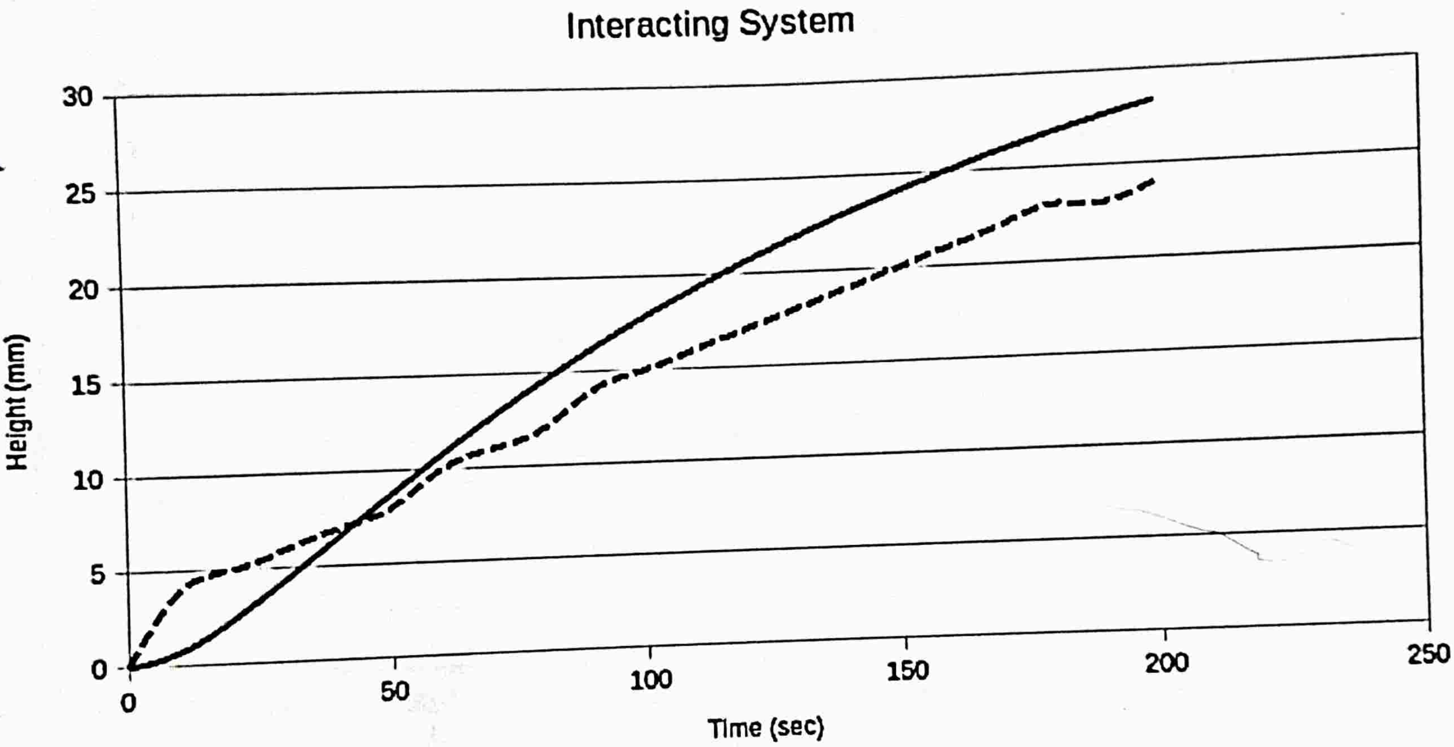
Same error.



(- - -) → H (Obs)
(——) → H (predicted)

Graph 2

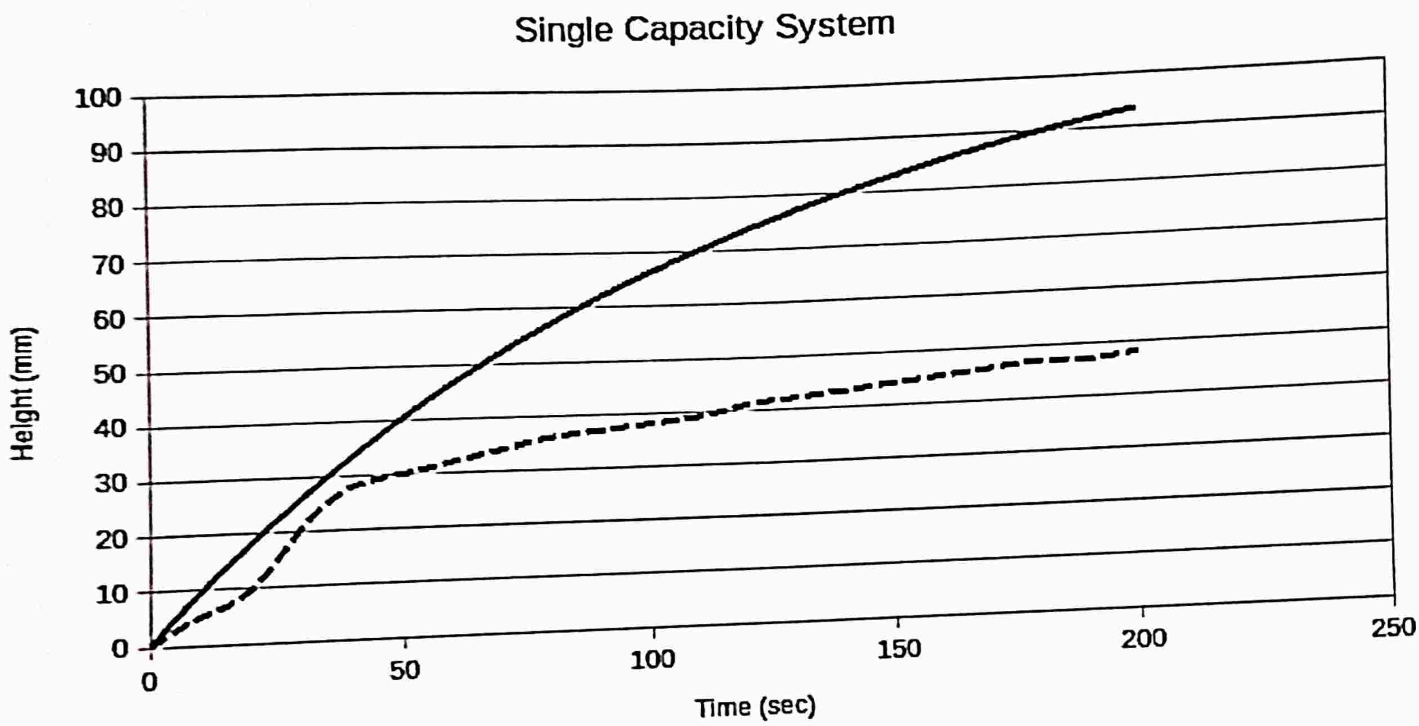
Same error.



(- - -) H (observed)
(——) H (predicted

Graph 3

Same. error.



(- - -) H (observed)

(——) H (predicted)

Graph 4.

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DATE | | SHEET NO.

Impulsive Input

flowrate = 80 LPH

Height initially = 20 mm

Sr. No.	Level ~~H (Observed)~~	H (observed)	steady Level	H (predicted)
1)	32	12	32	10.97
2)	28	8	32	10.044
3)	26	6	38	9.189
4)	24	8 4	32	8.407
5)	23	9 3	32	7.692
6)	22	2	32	7.0577
7)	20	0	32	6.4333
8)	22	2	32	5.389
9)	22	2	32	5.389
10)	22	2	32	4.93100
11)	22	2	32	4.51
12)	22	2	32	4.127
13)	22	2	32	3.77
14)	22	2	32	3.454

P.R.E.

Calculations :

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

Diameter of tank $= 92$ mm

Area tank $= \frac{\pi d^2}{4} = 6.647 \times 10^{-3} m^2$

1) Initial flow rate $= 50$ Lph (step response for single capacity system)

final flow rate $= 60$ Lph

Initial steady state tank level $= 80$ mm

final steady state tank level $= 127$ mm

$\Delta Q = 10$ Lph $= 2.78 \times 10^{-6} m^3/s$

$R = \frac{dH}{dQ} = \frac{47}{10} \times 3000 = 16920 \ s/m^2$

$\tau = A_1 R = 112.440$

h (predicted) $= AR(1 - e^{-t/\tau})$, for $t = 30$ sec $= 26.331$ mm

h (observed) $= |$level at 0 $-$ level at $t|$

$= |101 \text{ mm} - 80| = 21$ mm

2) Step response (first order non interacting)

Initial steady state water level (tank 2) $= 33$ mm

Final steady state water level (tank 2) $= 38$ mm

Initial flow rate $= 60$ Lph final flow rate $= 70$ Lph

$R_2 = \frac{dH}{dQ} = \frac{5}{10} \times 3600 = 18001.08$

$\tau_2 = 11.969$ $(A_2 R_2)$ $\cancel{AR_2 = 73.646}$.

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$$h_{predicted} = AR_2\left(1 - \frac{\tau_1\tau_2}{\tau_1-\tau_2}\left(\frac{e^{-t/\tau_1}}{\tau_2} - \frac{e^{-t/\tau_2}}{\tau_1}\right)\right)$$

$$= 11.968$$

$$h_{obs} = (33 - 38) = 5mm$$

8) ~~volume added~~ Initial flowrate = 70 LPH (step response for order interacting system)
Final " " = 80 LPH

Tank 2 (initial level) = 44mm
(final level) = 52mm

Tank 3 (initial level) = 52mm
final level = 75mm

$$R_2 = \frac{2dH_2}{dQ} = 2\frac{8}{10}\times 3600 = 5760$$

$$R_3 = \frac{dH_3}{dQ} = \frac{23}{10}\times 3600 = 8280$$

$$\tau_2 = AR_2 = 37.262 \qquad b = \frac{1}{\tau_2} + \frac{1}{\tau_3} + \frac{A_1R_3}{\tau_2\tau_3} = 0.071$$

$$\tau_3 = AR_3 = 55.03$$

$$\alpha = -\frac{b}{2} + \sqrt{\left(\frac{b}{2}\right)^2 - \frac{1}{\tau_2\tau_3}} = -0.0078$$

$$\beta = -\frac{b}{2} - \sqrt{\left(\frac{b}{2}\right)^2 - \frac{1}{\tau_2\tau_3}} = -0.0632$$

$$h_{predicted} = AR_2\left[1 - \frac{\frac{e^{\alpha t}}{\alpha} - \frac{e^{\beta t}}{\beta}}{\frac{1}{\alpha} - \frac{1}{\beta}}\right] = 4.4105$$

$$h_{obs} = (58 - 52) = 6mm$$

P.R.E.

9.) for impulsive single step input :-

$$A_1 \frac{dH}{dt} + \frac{H}{R_1} = Q(t)$$

$$A_1 R_1 \frac{dH}{dt} + H = R_1 Q(t)$$

$$(A_1 R_1 s + 1) H = R_1 Q(s)$$

$$Q(s) = V = A(32-20)$$
$$= 12A$$

$$\Rightarrow H(t) = \frac{R_1 V}{A_1 R_1} e^{-t/A_1 R_1}$$

$$\Rightarrow H(t) = 12 e^{-t/A_1 R_1} + 20$$

At $t = 30$ sec,

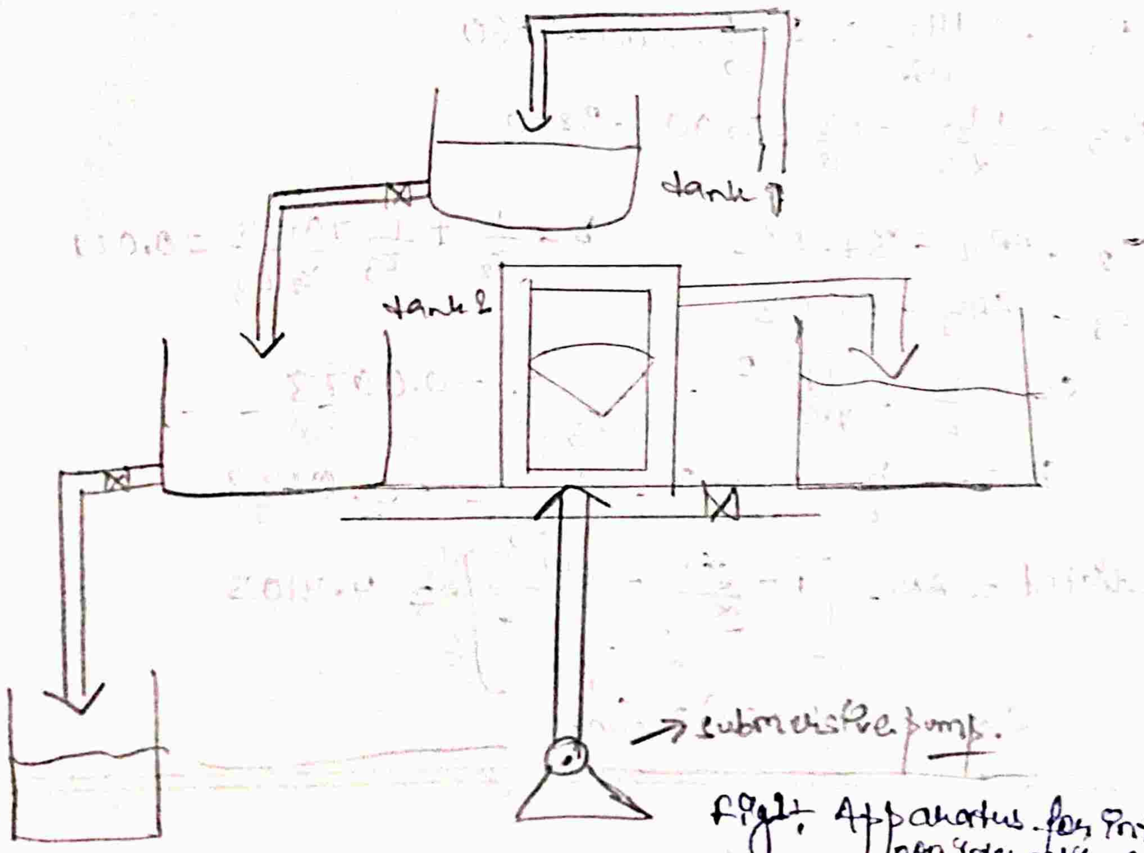


fig 1: Apparatus for interacting and non interacting system.

picture should be more clear with specification.

Discussions →

(i) From the experiment we concluded that the transport leg increases as we increase the number of tanks in series, because the response changes very slowly as the step function is introduced.

(ii) It was further concluded that both types of inputs (step and impulse), the time constants obtained were different and the time constant of tank 3 was always more than that of tank 2. This was due to the fact that in case of two interacting tanks, the flow Q_1 (from tank 3) will always be reduced with the buildup of level in the tank 2 as seen during experimental study.

(iii) Therefore, it can be finally concluded that in order to maintain a steady state in order to obtain ~~a steady~~ best results, it is recommended to check the sensitivity of rotameter prior to commencement of experiment.

(iv) It is also recommended that the input changes (step or impulse) should be instantaneous so as to reduce errors.

Precautions

(i) Calibrate all the instruments to reduce error.

(ii) Ensure that the setup is assembled correctly with all conditions securely tightened.

(iii) keep the set up dust free.

Results :

All the required calculations has been done.
Graphs have also been plotted between height (mm) that the observed and predicted height versus time (sec).

(i) step response for non interacting system (first order)

$h_{observed} = 5mm$ $h_{predicted} = 4.968$

(ii) impulse response for single step. ~~non interacting~~ system (first order)

$h_{observed} = 24mm$ $h_{predicted} =$ ~~28~~ $24 mm$

(iii) step response for single capacity system

$h_{observed} = 21 mm$ $h_{predicted} = 26.33 mm$

(iv) step response for first order interacting system

$h_{observed} = 6mm$ $h_{predicted} = 4.41 mm$

~~(v) impulse response for interacting system~~

~~$h_{observed} =$~~ ~~$h_{predicted} =$~~

INDIAN INSTITUTE OF TECHNOLOGY

DATE 03/08/23 | Exp-06 Calibration of Thermocouple and Resistance Thermometer | SHEET NO.

1.a) Aim

- To calibrate a thermocouple with the help of a mercury filled thermometer.
- To calibrate a resistance thermometer (RTD) with the help of a mercury filled thermometer.

2. Objective

The objective of this experiment is to calibrate an RTD (Resistance Temperature Detector) and thermocouple using a mercury-filled thermometer as a reference. This involves creating a controlled environment to apply known temperatures, recording resistance or voltage values from RTD and thermocouple and comparing them to readings from the reference thermometer. Deviations needs to be identified and necessary adjustments are made to align the measurements.

3.) APPARATUS REQUIRED

(i) Resistance Thermometer (RTD)
(ii) Mercury-filled thermometer
(iii) Beakers
(iv) Thermocouple

(v) Water Bath

(vi) Stirrer,

4) THEORY

The calibration process for an RTD and a thermocouple, utilizing a mercury filled thermometer as reference, is grounded in the principles of accurate temperature measurement. RTDs exploit the linear relationship between electrical resistance and temperature. Thermocouples harness the seebeck effect, generating a voltage porportional to temperature difference across dissimilar metals.

The calibration procedure involves subjecting the RTD and thermocouple to controlled temperature variations while concurrently monitoring the mercury thermometer's readings. Collected data facilitate the creation of calibration curves, mapping the sensor's output signals against the reference thermometer's values.

5.) PROCEDURE

- The main switch was switched on and the power of heater and stirrer speed were set.
- Readings of RTD, thermocouple and mercury filled thermometer were noted at intervals of 5°C of mercury filled thermometer temperature during heating.
- Then readings of RTD, thermocouple and mercury filled thermometer were noted at intervals of 5°C of mercury filled thermometer temperature during cooling.
- The thermocouple and RTD readings were plotted against the temperature of mercury filled thermometer.

6.) OBSERVATIONS

Table. 6.1 Title? Increasing

Temperature °C	RTD °C	Thermocouple Voltage (mV)
37	40	0.1
42	45	0.2
47	50	0.3
54	55	0.4
60	60	0.6

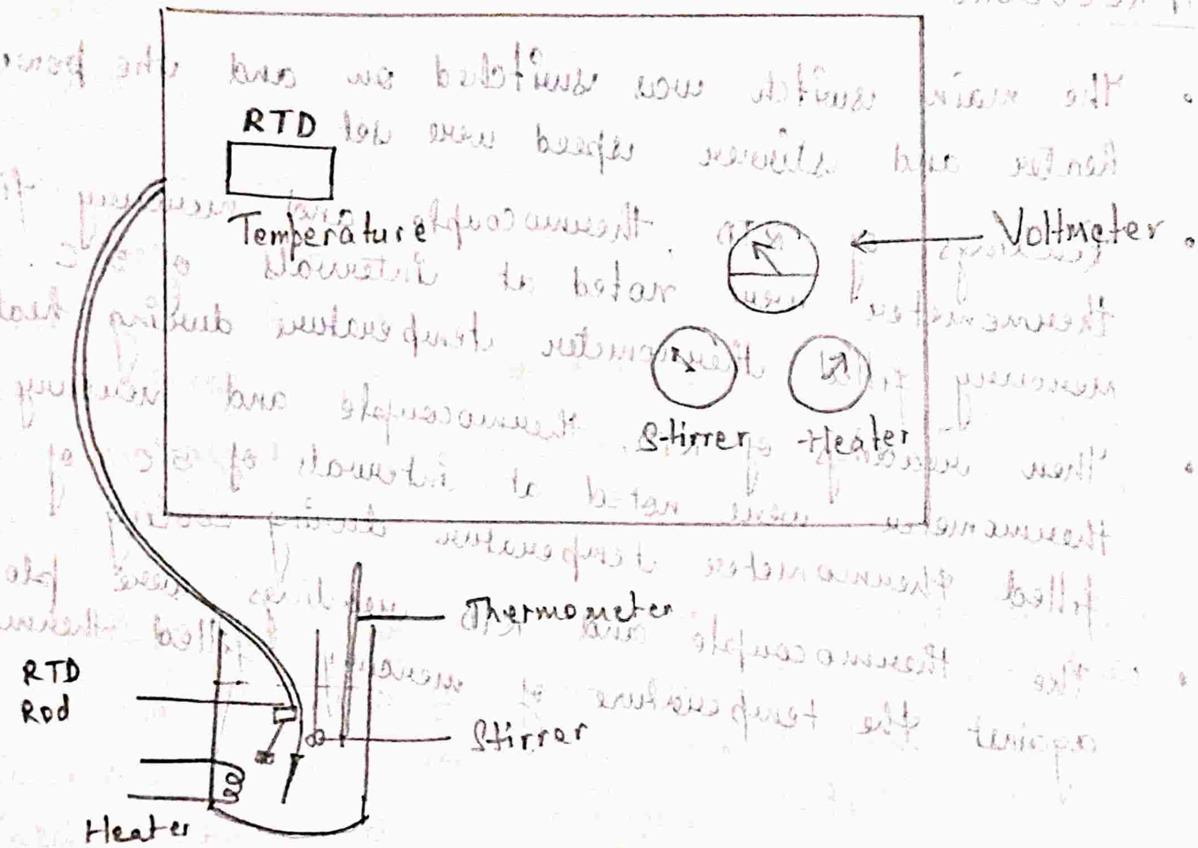
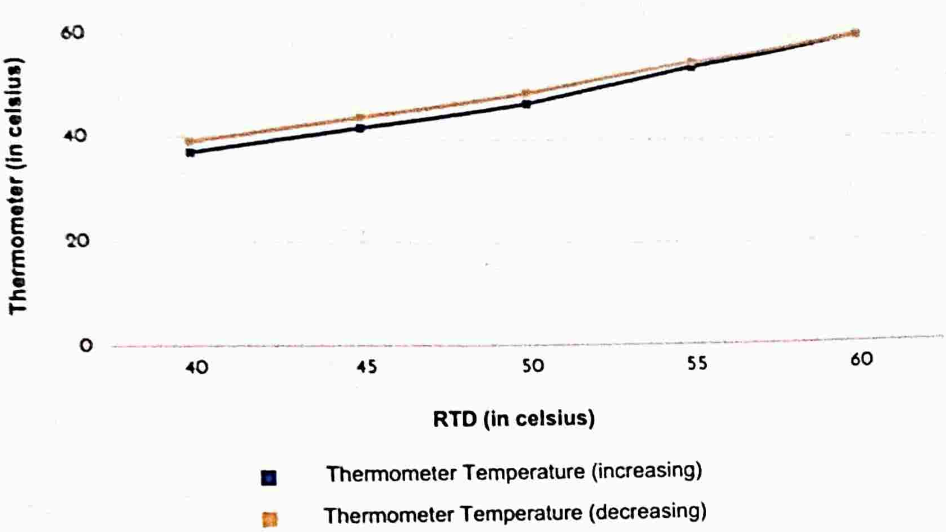


Fig. 1: Experimental setup to calibrate RTD and thermocouple.

7.) GRAPHS

~~Graph 6.1~~ Fig 2.

Thermometer vs RTD



~~Graph 6.2~~ Fig 3.

Thermometer vs Thermocouple

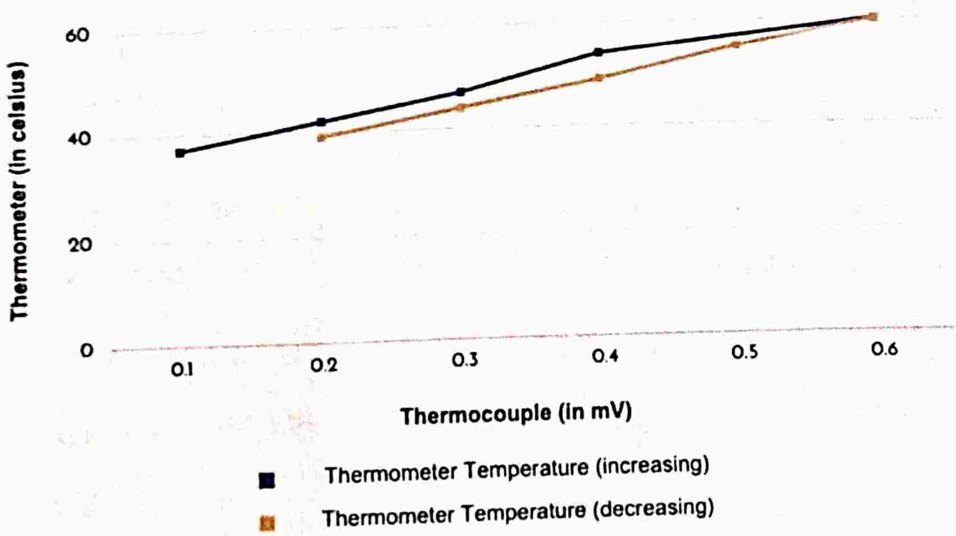


Table 6.2 Decreasing

Temperature celsius (°C)	RTD celsius (°C)	Thermocouple Voltage (mV
60	60	0.6
55	55	0.5
49	50	0.4
44	45	0.3
39	40	0.2

8.) DISCUSSION

- Continuous stirring mechanism was provided to ensure uniform heating.
- Hysteresis was more in case of thermocouple than RTD.
- The accuracy of reference instrument (thermometer) is higher than the instrument to be calibrated.
- One possible source of error is the time lag while noting down the readings of thermometer, RTD and Voltmeter.

9.) CONCLUSION

Our experiment revealed that the thermocouple exhibited more hysteresis compared to RTD. Through our calibration process, we successfully refined the accuracy of both the RTD and thermocouple readings, a critical aspect for a range of applications. This precision holds significance in scientific, industrial and technological realms, contributing to better processes, product quality and research outcomes.

a.) Objective: The objective of this experiment was to investigate the characteristics of a flapper nozzle system. The flapper nozzle system is a device commonly used in fluid mechanics to control the flow of fluids through a nozzle using a hinged flapper. The experiment involved analysing the relationship between the flow rate of a fluid and the angle of the flapper, as well as the effects of different pressure differentials on the system.

b.) Aim: To study the characteristics of flapper nozzle system.

c.) Theory: The setup helps in understanding conversion of mechanical motion to pressure signal. It consists of flapper-nozzle mechanism, Dial gauge indicator, pressure gauges and air filter regulator. A regulated supply of pressure, usually over 20 psig, provides a source of air through the restriction. The nozzle is ~~open at the end where the gap exist~~ between the nozzle and flapper and air escapes in this region.

d.) Apparatus :- The experimental setup consisted of a flapper nozzle system attached to a fluid source, a pressure differential control system, and measurements. The key compounds included:

- flapper nozzle assembly with a hinged flapper.
- fluid reservoir & pump.
- Pressure differential control valve.
- flow rate measurement apparatus (flowmeter)
- Angle measurement device | Gap meast. device.

e.) Procedure :

1. Calibrate the angle measurement device.
2. Set up the pressure differential control system to maintain a constant pressure across the nozzle.
3. Gradually adjust the gap of the flapper from fully closed to fully opened.
4. record signal pressure and nozzle gap and repeat the set of observation till 100 μm gap.

f.) Observations : $P_{total} = 1.2\ kg/cm^2 = 15$ psig

S.No.	Nozzle Gap (µm)	Signal Pressure (Psig)
1.	20	9
2.	30	8
3.	40	6
4.	50	5
5.	60	4
6.	70	3.8
7.	80	3
8.	90	3.
9.	100	3

Table - 7.1 flapper Nozzle system

g.) Results :

To calculate gain of flapper nozzle system.

Gain of flapper nozzle system

$$= \frac{\text{change in signal pressure}}{\text{corresponding change in nozzle gap}} \quad \text{psig}/\mu m$$

$$= \frac{7-4}{60-35} = 0.12 \ \text{psig}/\mu m$$

$$= 120 \ \text{psig}/mm$$

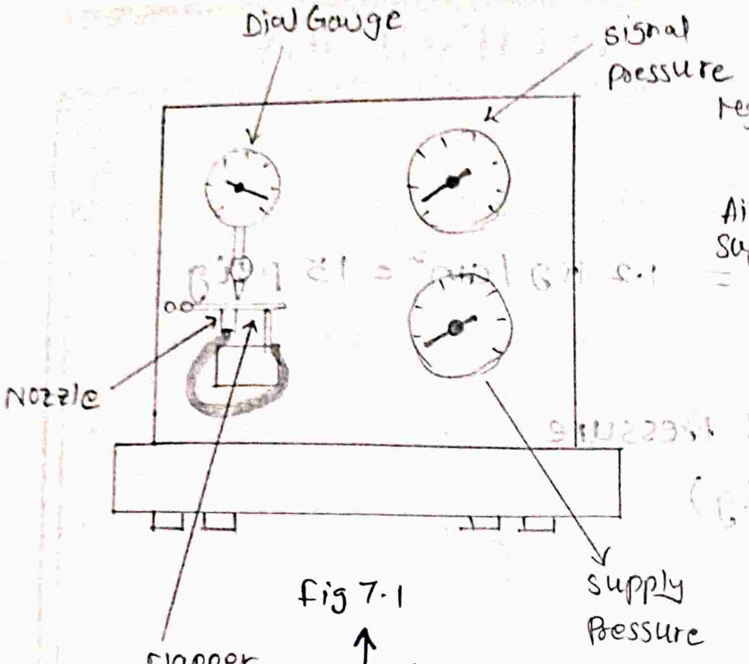


fig 7.1

distance ?

Apparatus : flapper-Nozzle system

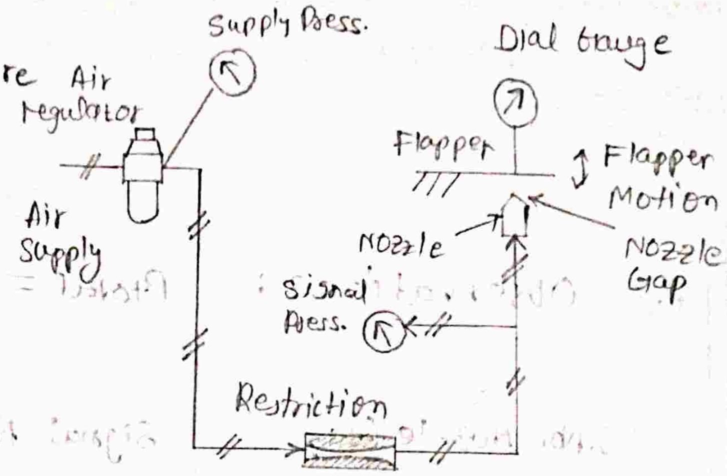


fig 7.2 :

schematic of ?

Should be inline

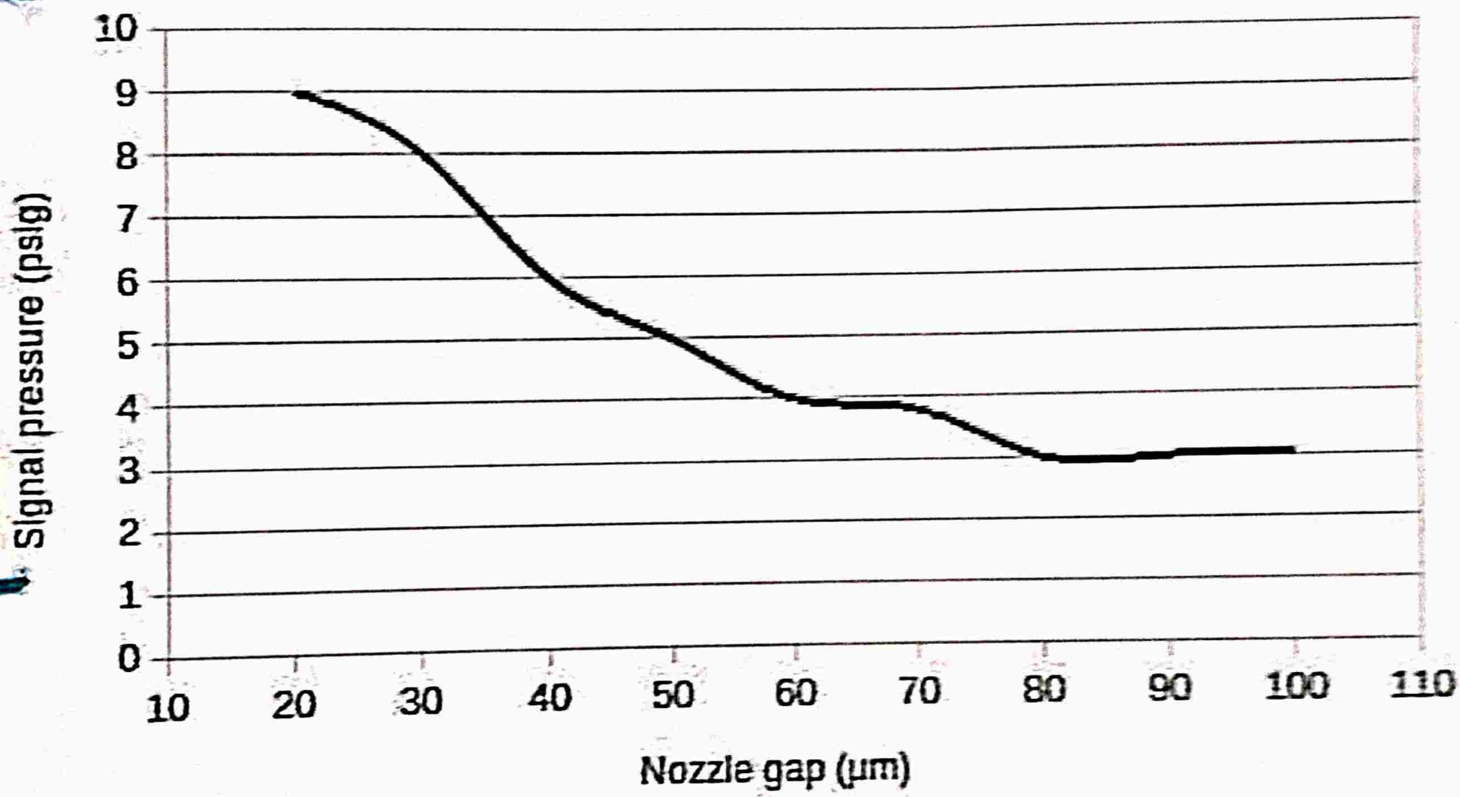
h.) Discussion: The observed relationship between flapper angle/nozzle gap and flow rate is consistant with theoretical expectations. As the flapper angle increases, the effective flow area enlarges, allowing more fluid to pass through the nozzle.

g.) Conclusion: The experiment successfully demonstrated the characteristic of a flapper nozzle system. The relation between nozzle gap and pressure differential was established, highlighting the system's responsiveness to these parameters. This knowledge can be applied to optimize the design and operation of flapper nozzle system in various engineering applications.

——— x ———

figure ?

1. ~~Graph~~ 7.1 Flapper-Nozzle system



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Experiment - 8

Study of characteristics of Differential Pressure Transmitter

SHEET NO.

a) Objectives :- <i> To calculate the change in ammeter current with ~~5~~ every 5 unit change in the height of the fluid column.

<ii> To calculate the average change in ammeter reading with respect to the change in height of the fluid column ~~and then~~ to study the characteristics of differential pressure transmitter.

b) Aim :- To study the working and characteristics of a differential pressure transmitter.

c) Theory :- This setup helps us to understand the real principle behind working of the Differential Pressure Transmitter (DPT). Here, through this apparatus, we can gain insights of how one kind of signals can be converted into other kind of signals. This involves emptying a filled up column of water upto a certain height and then noting the change in height of column after the emptying is done. This change in height leads to a corresponding change in pressure at the base of the column given by $\rho g h$ [where h is the change in height of the liquid and ρ the density]. The apparatus has a diaphragm connected to the lower part of the column. With the change in height of the water column the diaphragm shifts of. For a decrease in height, the diaphragm shifts backwards and for an increase, it shifts forward. This diaphragm is further attached to parallel capacitor plates. Due to the movement of diaphragm, the capacitor plates further move closer (for an increase in water level) and away (for a decrease in the water level). This changes the distance between the plates of a capacitor, which further changes its capacitance given by $\boxed{C = \frac{A\varepsilon}{d}}$. Due to this,

the charge stored in the capacitor, given by $\boxed{Q = CV}$ further changes. Thus there would be a flow of charge (outflow or inflow) through the capacitor, which would be measured by an ammeter attached to it. Thus, the ammeter would give the current flow for the given height (pressure) variation. Thus converting one kind

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of signals (pressure variation signals) to another kind of signals (electric signals). ~~Thus~~

d) Apparatus :- The apparatus consisted of a transparent column which would contain filled water, as shown in fig. 1. (a). A calibrated scale beside it as in fig 1. (b) and the other equipments like :-

- Ammeter
- Pipette
- Beaker to collect water

(e) Procedure :-

<i> Switch on the mains supply to the setup.

<ii> Take the ammeter reading and ensure that the needle is initially at zero point.

<iii> Fill up the ~~whole~~ column with water (upto around 40cm) using pipette.

<iv> Now, open the stopper present at the bottom of the column and allow the water to flow out in such a way that there is a variation of 5cm in

height of the column. Measure the current and change in current accordingly (in mA).

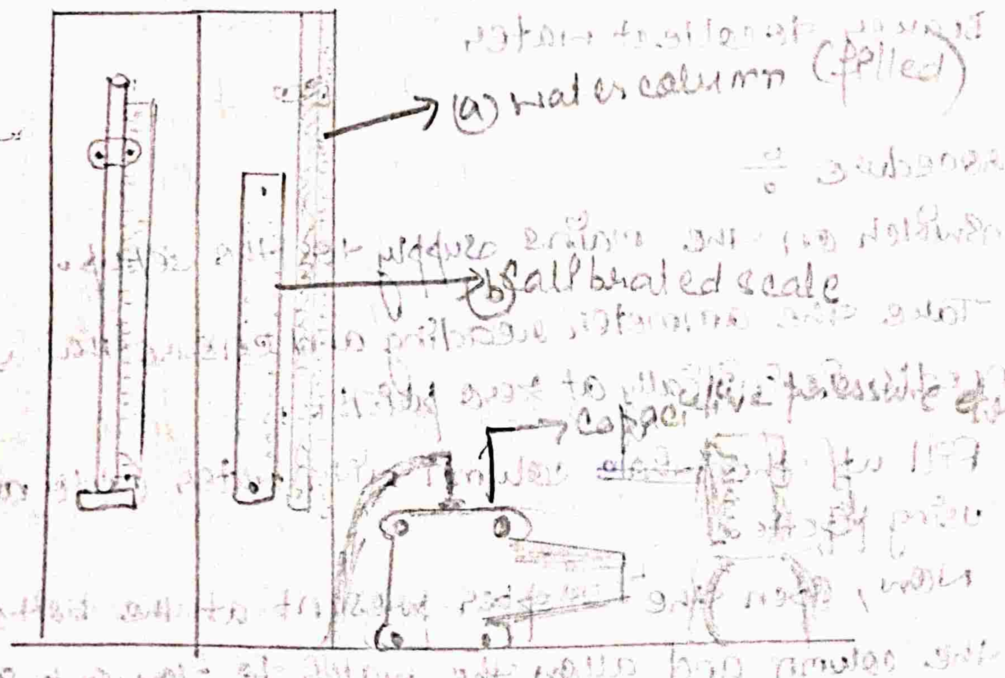
(v) Note the ammeter reading and the pressure variation in a notebook.

(vi) Now, after whole of the water has been emptied and ammeter has reached zero again, start filling the tube with water such that the height progresses in lot of 5cm.

(vii) Measure the change in the ammeter readings again and note them separately.

(viii) continue doing this till the height reaches around 40cm.

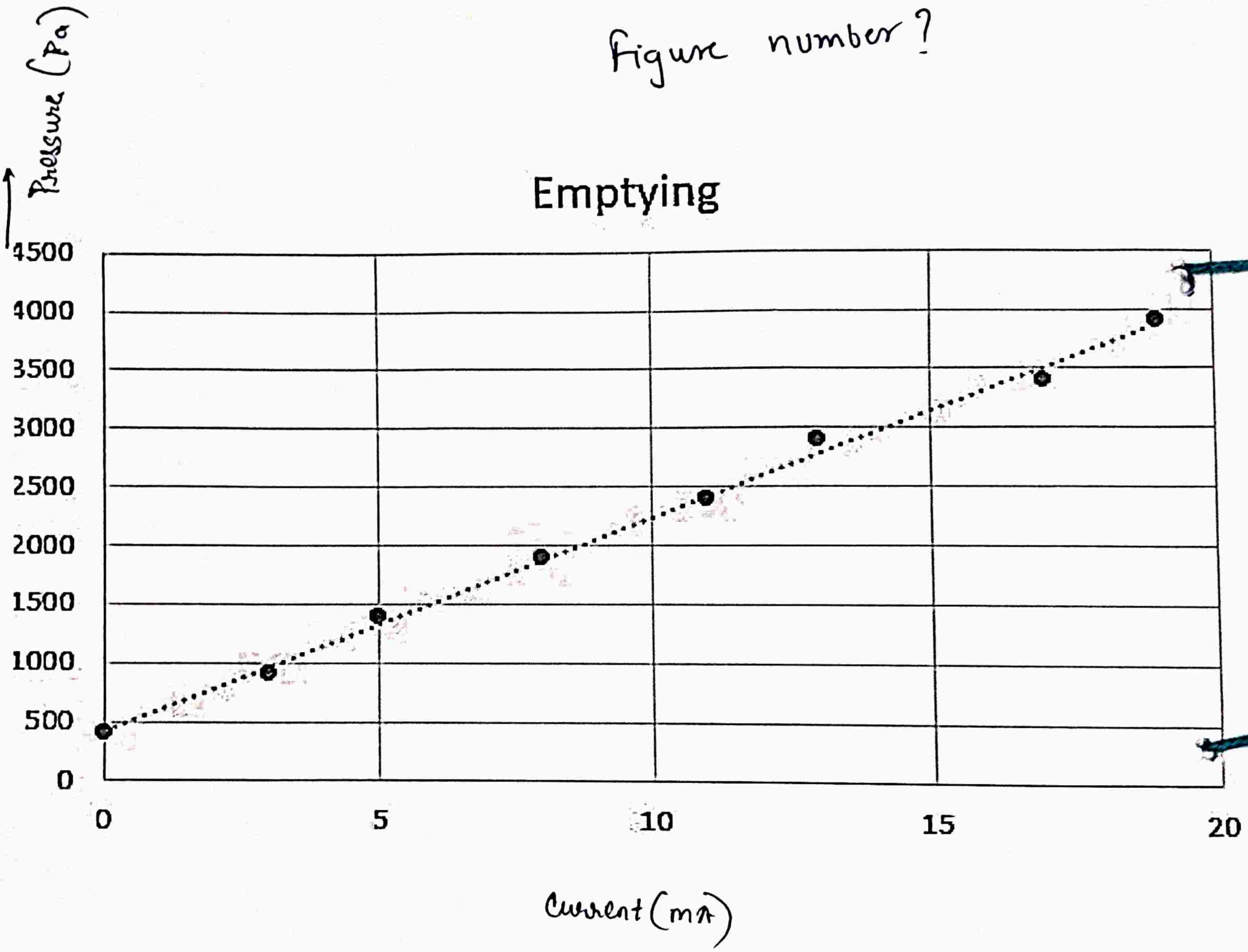
(ix) Plot the graph for the change in pressure during both filling up and emptying time.



fig' (Apparatus for the study of differential pressure transmitter characteristics)

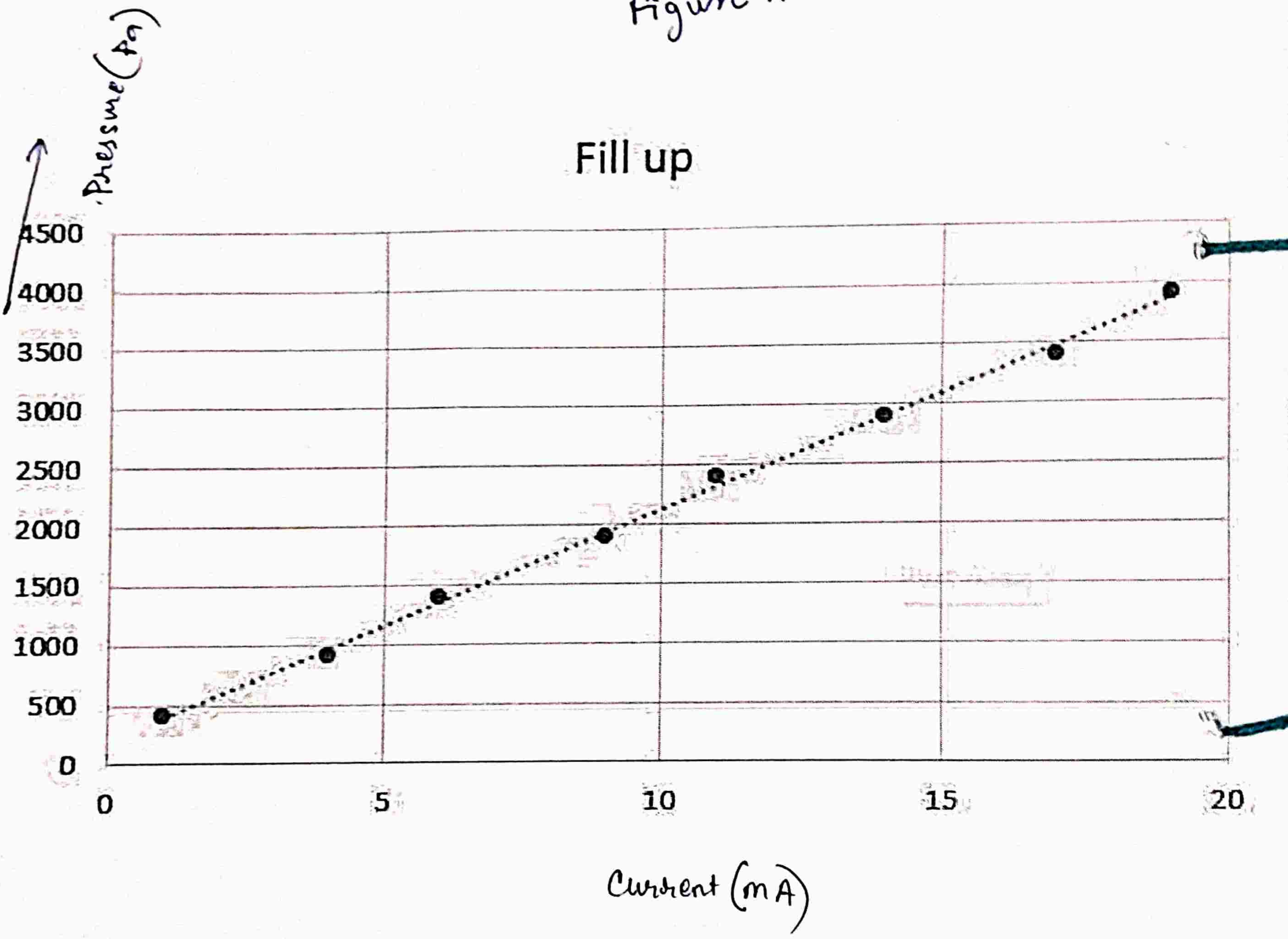
figure number

Figure number?



Graph 1
(for emptying the column)

Figure number ?



Graph 2 (for fillup)

(f) Observations :

For emptying. Initial current = 1mA

Sr NO	Height of water (cm)	Current ~~Pressure~~ (mA)	Pressure ~~Current~~ (Pa)
1.)	39	20-1=19	3900
2.)	34	18-1=17	3400
3.)	29	14-1=13	2900
4.)	24	12-1=11	2400
5.)	19	09-1=08	1900
6.)	14	06-1=05	1400
7.)	09	04-1=03	900
8.)	04	01-1=00	400

(Table 1)

For fillup.

Sr no.	Height of water (cm)	Current ~~Pressure~~ (mA)	Pressure ~~Current~~ (Pa)
1.)	04	02-1=1	400
2.)	09	05-1=4	900
3.)	14	07-1=06	1400
4.)	19	10-1=09	1900
5.)	24	12-1=11	2400
6.)	29	15-1=14	2900
7.)	34	18-1=17	3400
8.)	39	20-1=19	3900.

(Table 2.)

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(f) Observations :

For emptying. Initial current = 1mA

Sr NO	Height of water (cm)	Current ~~Pressure~~ (mA)	Pressure ~~Current~~ (Pa)
1.)	39	20-1=19	3900
2.)	34	18-1=17	3400
3.)	29	14-1=13	2900
4.)	24	12-1=11	2400
5.)	19	09-1=08	1900
6.)	14	06-1=05	1400
7.)	09	04-1=03	900
8.)	04	01-1=00	400

(Table 1)

For fillup.

Sr no.	Height of water (cm)	Current ~~Pressure~~ (mA)	Pressure ~~Current~~ (Pa)
1.)	04	02-1=1	400
2.)	09	05-1=4	900
3.)	14	07-1=06	1400
4.)	19	10-1=09	1900
5.)	24	12-1=11	2400
6.)	29	15-1=14	2900
7.)	34	18-1=17	3400
8.)	39	20-1=19	3900.

(Table 2.)

P.R.E.

(g) Results :-

slope of ΔP vs ΔI graph for emptying part :-

$$\frac{\Delta P}{\Delta I} = 180.8725$$

Slope of ΔP vs ΔI graph for fill up part :-

$$\frac{\Delta P}{\Delta I} = 193.1464$$

$\therefore$ Average slope = 187.0095

$$\Rightarrow \frac{\Delta P}{\Delta I} = 187.0095$$

$\Rightarrow$ for every 1mA rise in current, the corresponding change in pressure is 187.0095 Pa and height of the column changes by 1.87 cm.

(h) Discussion :- The observed values for current ~~at~~ isn't varying ~~ty~~ linearly with pressure change in both emptying and fill up parts. This is because there might be ~~an~~ leakage of water from the stop cock or may be the ammeter won't be sensitive enough to measure those variations. Also, the slopes for both emptying and filling up lots were different, this also might be because of the ammeter sensitivity, also may be that while emptying some of the fluid would have remained in the column.

(i) Conclusion :- Thus a differential pressure transmitter makes use of a capacitor / capacitive plates to convert the pressure drop signals into the current variation signals and then calibration is done.

DATE | Experiment - 9 : First order and, second order system | SHEET NO

Aim: To study step response of ~~water molecule~~ manometer filled with water and mercury respectively.

OBJECTIVES: The objective of this experiment is to improve our understanding of pressure measurement systems, enhance their accuracy and reliability and guide their design, calibration and application in various industries and fields. Our objective is to study the dynamic response of a second order system to a step change.

THEORY: The dynamic response of a second-order system can be described by a second order differential equation

$$y(t) = K \times M \times \left\{ 1 - e^{-\psi t/\tau} \left[\cos\left(\frac{\sqrt{1-\psi^2}}{\tau} t\right) + \frac{\psi}{\sqrt{1-\psi^2}} \sin\left(\frac{\sqrt{1-\psi^2}}{\tau} t\right) \right] \right\}$$

where,

$y(t)$ = response at any time t

K = gain factor

M = magnitude of step change

ψ = damping coefficient

$$= \frac{8 L \mu}{\rho g D^2} \sqrt{\frac{2g}{L}}$$

L = length of column

μ = dynamic viscosity.

EXPERIMENTAL PROCEDURE:

- Make sure that level of liquid in both arm of manometer is same
- Adjust the valve depending on the manometer used.
- Close the vent connection by putting a finger or palm on it, to apply a step change.
- Make a video of the oscillations in the manometer.
- Decrease the playback speed of the video and note the liquid level with respect to the time.

EXPERIMENT-9 PART-I

The liquid used in the manometer is water.

Manometer Data:

- Manometer fluid: Water
- Dynamic viscosity = 0.001 kg/ms
- Mass density = 998 kg/m³
- Column length = 1.050 m
- Tube diameter = 0.022 m

CALCULATIONS

From the response curve of 2nd order system

Rise time (t_r) =

Damping coefficient (ψ) = $\dfrac{8L\mu}{\rho g D^2}\sqrt{\dfrac{2g}{L}}$

Where $\rho = 998\ kg/m^3$ $L = 1.050\ m$

$\mu = 0.001\ kg/ms$. $D = 0.022\ m$

Fig. 9.1 Theoretical plot of y/km (cm) vs time (s)

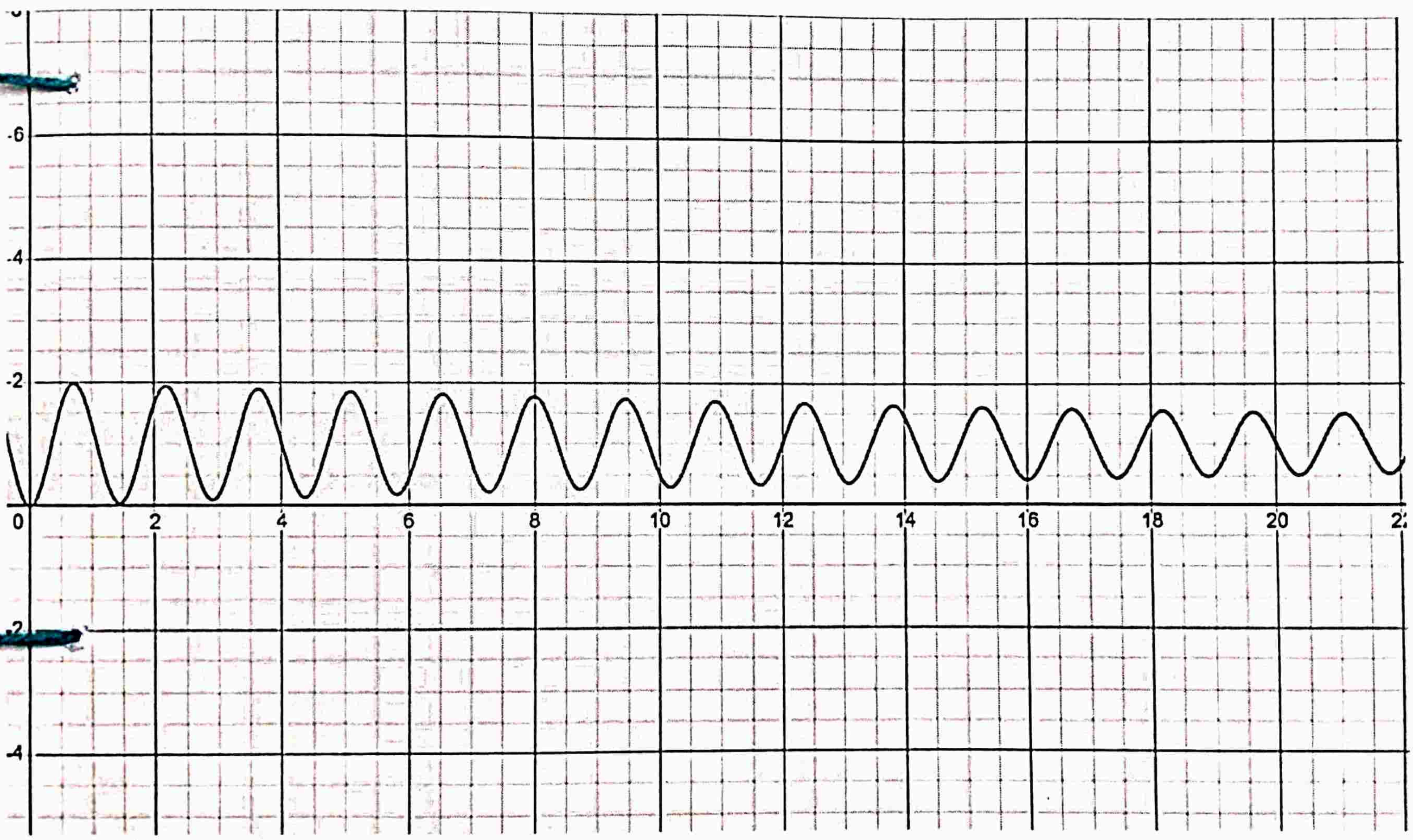

Fig 9.2: Experimental plot of displacement (cm) vs time (s) (Water is used in manometer)

Time(s)	Displacement(cm)	Displacement wrt to stable point(cm)
0	125	0
1	125	0
2	270	145
3	10	-115
4	20	-105
5	229	104
6	210	85
7	200	75
8	82	-43
9	140	15
10	114	-11
11	110	-15
12	105	-20
13	151	26
14	152	27
15	105	-20
16	110	-15
17	112	-13
18	130	5
19	120	-5
20	130	5
21	129	4
22	130	5
23	120	-5
24	125	0
25	132	7
26	134	9
27	125	0
28	125	0
29	125	0
30	125	0
31	124	-1
32	124	-1
33	125	0
34	125	0
35	125	0
36	125	0

Table: 9.1
displacement vs time in water filled manometer

$\varphi = 7.66 \times 10^{-3}$

Decay ratio (DR) $= e^{\left(\frac{-2\pi\varphi}{\sqrt{1-\varphi^2}}\right)} = 0.9530$

Overshoot $= \sqrt{DR} = 0.97622.$

Natural frequency $\omega_n = 2\pi\sqrt{\frac{2g}{L}} = 27.14$ rad/s

Frequency of damped oscillation

$= \frac{\omega_n \times \sqrt{1-\varphi^2}}{2\pi}$

$= \cancel{27.14} \; 4.3192$ cps.

Characteristic time (τ) $= \frac{2\pi}{\omega_n} = 0.2315$ s

ξ (Damping co-efficient) ?

EXPERIMENT-9 PART:2:

The manometer is filled with mercury.

MANOMETER DATA.

Manometer fluid: Mercury

Dynamic viscosity = 0.0016 kg/ms.

Man density = 13550 Kg/m^3

Column length = 760 mm

Tube diameter = 0.005m

CALCULATIONS

Rise time (t_r) = ~~[illegible]~~

Damping coefficient (φ) = $\frac{8L\mu}{\rho g D^2}\sqrt{\frac{2g}{L}}$

where ρ = 13550 kg/m^3

μ = 0.0016 kg/ms

L = 0.76 m

D = 0.005 m

$\varphi = 1.473 \times 10^{-2}$

Decay ratio (DR) = $e^{-\frac{2\pi\varphi}{\sqrt{1-\varphi^2}}}$ = 0.9116

Overshoot = $\sqrt{DR}$ = 0.9548.

Natural frequency = $\omega_n = 2\pi\sqrt{\frac{2g}{L}} = 31.9081$

Frequency of damped oscillation

$$= \frac{\omega_n \sqrt{1-\varphi^2}}{2\pi}$$

$= 5.07832$ cps

Characteristic time $= \frac{2\pi}{\omega_n} = 0.1969$ s

DISCUSSION: Damping co-efficient (ξ) ?

(i) There is quite a difference between the graphs obtained for the theoretical and observational values. The observed value converges much faster.

(ii) As we will never know whether an overdamped system has reached steady state or not, most practical system are made to be underdamped.

(iii) Mercury used in manometer should be handled with care, since it is toxic.

CONCLUSION:

We ~~see~~ observe ~~????~~ the damping amplitude of liquid column in manometer in response to a step change.
We find that there is some differences between the theoretical and observational values.

Fig 9.3: Theoretical plot of y/Km (cm) vs time (s)
(Mercury is used in manometer)

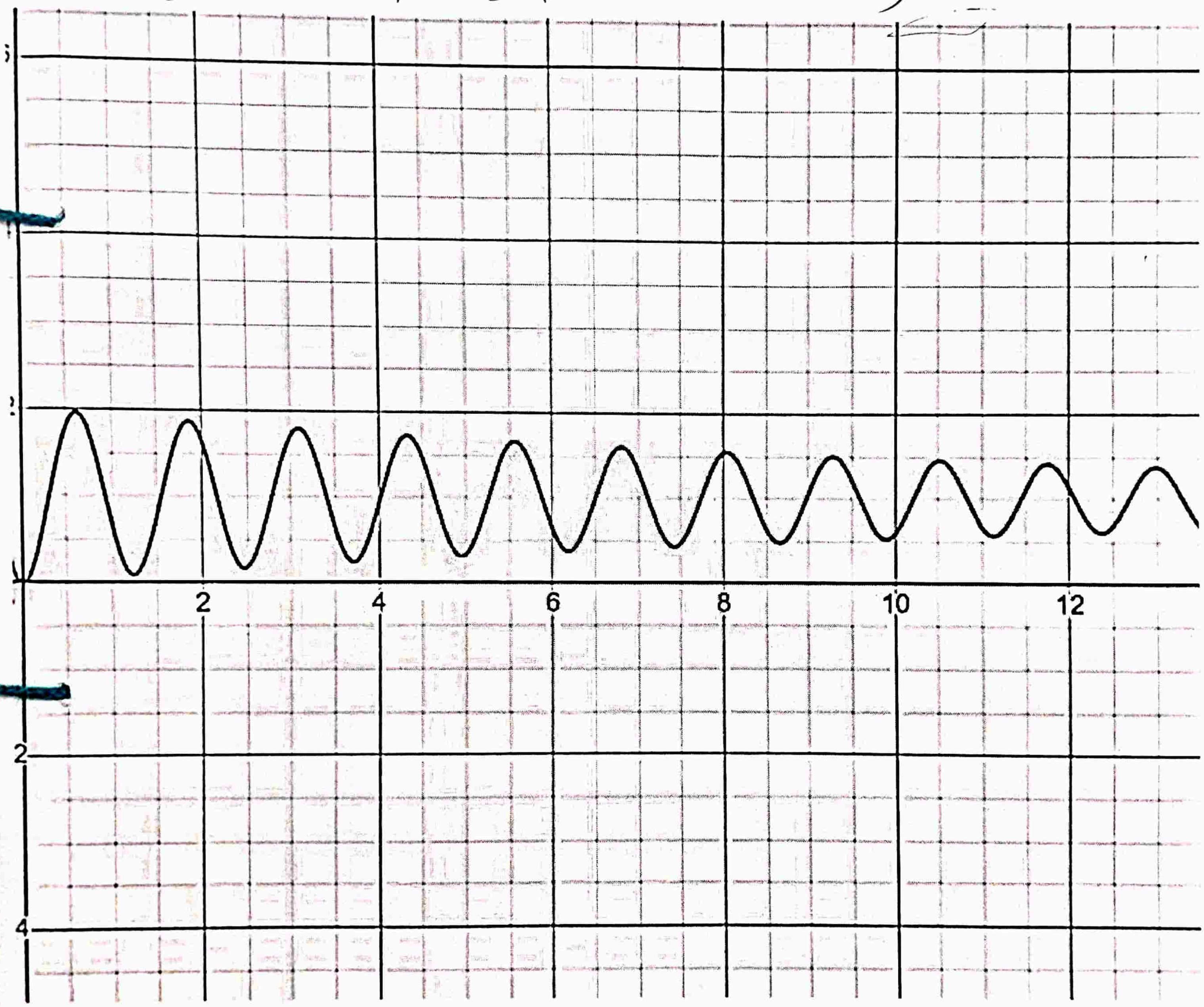

Fig 9.4: Experimented plot of displacement (cm) vs time (s)
(When Mercury is used in manometer)

Time(s)	Displacement(cm)	Displacement wrt stable point(cm)
0	-15	0
1	180	195
2	-110	-95
3	-50	-35
4	-20	-5
5	-10	5
6	-5	10
7	-15	0
8	-18	-3
9	-15	0
10	-15	0

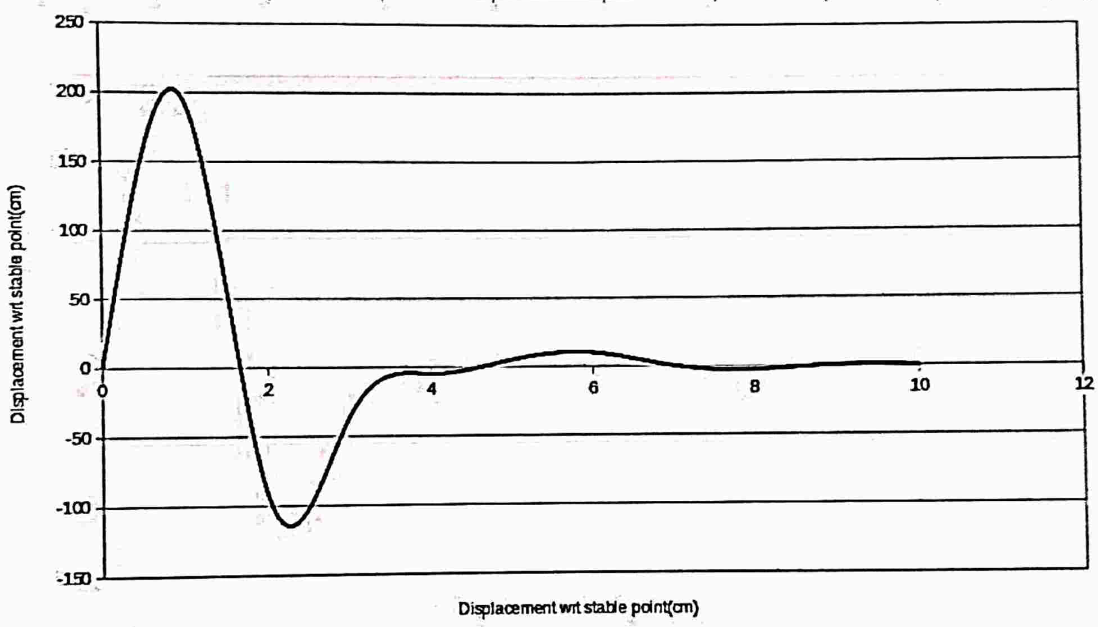

Table: 9.2
Displacement vs time in mercury filled manometer

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SHEET NO.

EXPERIMENT: 9.3

AIM: To study the transient response of the first order and second order reaction.

OBJECTIVES: The objective is study and analyse the temperature vs time plot in the thermometer and thermowell when applied a step change in temperature.

PROCEDURE:

- Fill the heating bath with clean water by opening the inlet valve of the heating bath.
- Heat the water to a higher temperature by switching on the heater.
- Put the thermometer in the water bath and note the steady state reading of the thermometer.
- Now stop heating and note the temperature reading at an interval of 10 secs.

THEORY:

~~Step ch~~
The dynamic response of 1st order type instruments to a sinusoidal change can be represented by

$$T\frac{d\theta}{dt} + \theta = A\sin\omega t$$

where θ = indicated temperature
t = time
A = amplitude.
ω = circular frequency

Soln.

$$\left[\frac{\theta}{A}\right] = \frac{1}{\sqrt{1+\omega^2 T^2}} \sin(\omega t - \phi)$$

$$\phi = \tan^{-1}(\omega T) = \text{lag angle}$$

The equation shows that

(i) output is a sine wave with frequency ω equal to that of the input signal.

(ii) the instrument lags the measured variable by a geometric angle ϕ where $\phi = \tan^{-1}(\omega T)$.

(iii) the amplitude is reduced.

CALCULATIONS:

1. Step change = Final temp − Initial temp = 46 − 30 = 16

2. Value of 63.2% of step:

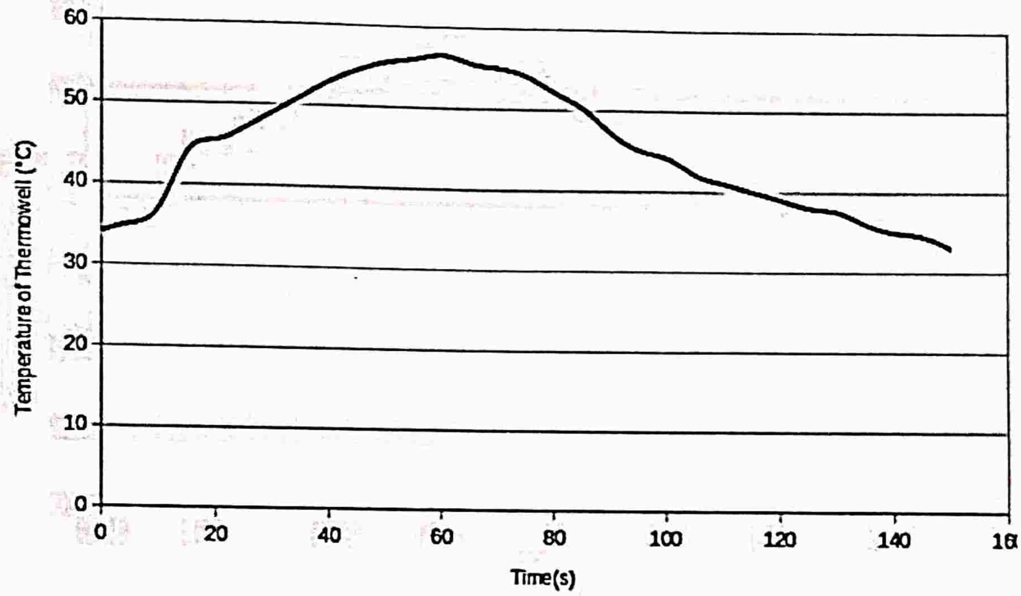
= 0.632 × (Final − Initial) + Initial

= 40.112

Time(s)	Temperature of Thermowell(°C)	Temperature of Thermometer(°C)
0	34	30
5	35	33
10	37	35.5
15	44	40
20	45.5	42
25	47	43
30	49	44
35	51	45
40	53	45
45	54.5	45.5
50	55.5	46
55	56	46.5
60	56.5	45
65	55.5	41
70	55	37
75	54	35
80	52	33
85	50	32
90	47	31
95	45	31
100	44	31
105	42	31
110	41	30.5
115	40	30.5
120	39	30.5
125	38	30.5
130	37.5	30
135	36	30
140	35	30
145	34.5	30
150	33	30

Table : 9.3
Temp vs time in thermowell & thermometer.

Fig 9.5:
Temp. of thermowell (°C) vs time(s)



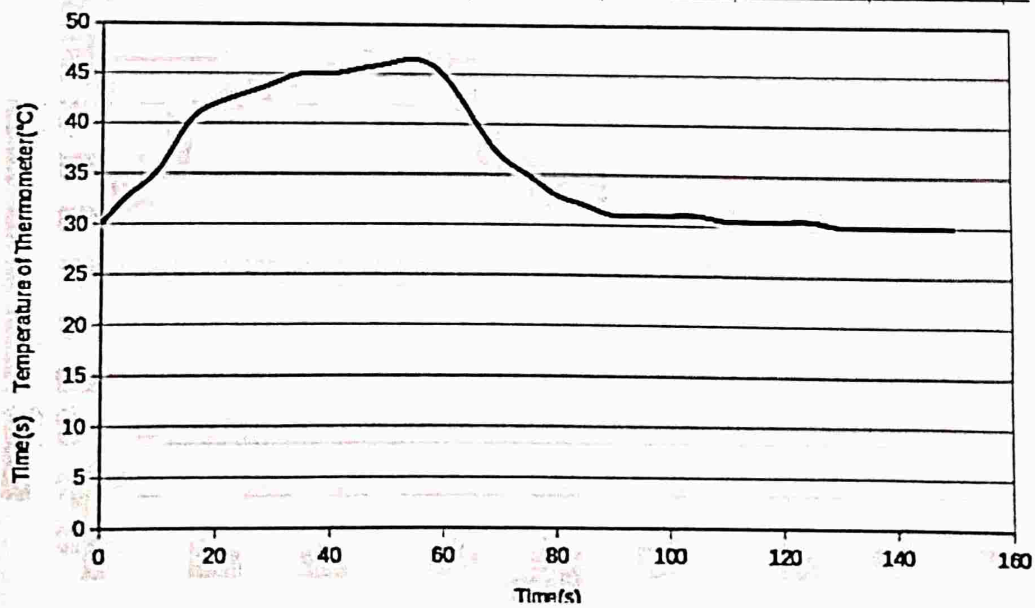
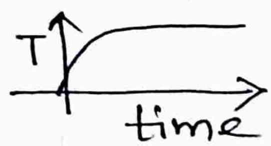


Fig 9.6: Temp. of thermometer (°c) vs time (s)

For a first order system the response curve should be exponential.



* The objective of the experiment was to calculate the time constant and see if adding resistance (thermowell) brings change to the τ (time constant) of the system.

DISCUSSION:

- The 1st order control system are not stable when used with ramp inputs.
- With ramp and parabolic inputs as their response increase at an infinite amount of time
- As the impulse and step inputs have bounded output, the 1st order control system are stable.

CONCLUSION:

The observed step response matches closely with the first order step response.

—— x ——

8/10 Rajdeep

INDIAN INSTITUTE OF TECHNOLOGY

DATE 31/8/23 | Study of P/I and I/P converter | SHEET NO.

AIM :- To study the operation of P/I and I/P converter.

OBJECTIVE :-

(i) To study the working principle and calibration pressure of P/I and I/P converter.

(ii) To study the linearity, hysteresis, accuracy and repeatability of I/P and P/I converter.

THEORY :-

P/I converter :-

A P/I converter converts a pressure signal to an electrical signal. The input signal is applied to a diaphragm, which deflects in proportion to the pressure. The deflection of the diaphragm is then converted to an electric signal by sensor, such as a strain gauge or piezoelectric sensor.

The output signal of a P/I converter is proportional to the input signal. The proportionality constant is called the gain of the converter. The gain of a P/I converter can be adjusted by charging the calibration of the converter.

I/P converter :-

An I/P converter converts an electrical signal to a pressure signal. The input signal is applied to a coil, which creates a magnetic field. The magnetic field is then used to move a diaphragm, which generates a pressure signal.

The output signal of an I/P converter is proportional to the input signal. The proportionality constant is called the gain of the converter.

PROCEDURE (I/P converter):-

(i.) Put the current source/sink indicator source mode by pressing and confirm source LED is glowing.

(ii.) Give current input in the step of 4mA from 4 to 20mA by slowly rotating the knob of source indicator.

(iii.) Note down corresponding pressure on output pressure gauge in psig.

(P/I converter) :-

(i) Put current source/sink indicator sink mode by pressing and confirm sink LED is glowing.

(ii) Set input signal to 3 psig and check the output current as 4mA.

(iii) If the current is showing more or less than 4mA then adjust zero on the isolator.

(iv.) Give input signal in the step of 3 psig from 3 to 15 psig and check the output current.

(v.) Note down corresponding output current values.

OBSERVATION :-

1. Accuracy of I/P converter:-

Sl. No.	Input current (mA)	Standard Output Pressure (psig) (X)	Actual output Pressure (psig) (Y)	Deviation (psig) (Y) − (X)
1.	4	3	3	0
2.	8	6	6	0
3.	12	9	8	1
4.	16	12	10	2
5.	20	15	13	2

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2. Hysteresis of I/P converter:-

Sl. No.	Input current (mA)	Output Pres. (psig) (X)	Input current (mA)	Output Pres. (Y)	Hysteresis (psig)(Y)-(X)
	Increasing input current		Decreasing input current		
1.	4	4	4	3	1
2.	8	7	8	7	0
3.	12	10	12	9	1
4.	16	11	16	12	1
5.	20	13	20	13	0

3. Repeatability of I/P converter:-

Sl. No.	Input current (mA)	Output Pres. (Psig) (X)	Input current (mA)	Output Pressure (psig) (Y)	Deviation in output (psig) (Y) – (X)
1	4	3	4	4	1
2	8	6	8	7	1
3	12	7	12	10	3
4	16	10	16	11	1
5	20	13	20	13	0

1. Accuracy of P/I converter:-

Sl. No.	Input Press (psig)	Standard Output current (mA) (X)	Actual Output current (mA) (Y)	Deviation (mA) (Y) – (X)
1.	3	4	6.5	2.5
2.	6	8	10.5	2.5
3.	9	12	14.5	2.5
4.	12	16	18.0	2.0
5.	15	20	20	0.0.

2. Hysteresis of P/I converter

Sl. No.	Input Press (psig)	Output current (mA) (X)	Input Press (psig)	Output current (mA) (Y)	Hysteresis (mA) (Y) - (X)
	Increasing input current		Decreasing input current		
1.	3	6.6	3	6.3	0.3
2.	6	10.4	6	10.2	0.2
3.	9	14.2	9	14.1	0.1
4.	12	18.3	12	18.2	0.1
5.	15	20	15	20	0.0

3. Repeatability of P/I converter :-

Sl. No.	Input current (mA)	Output Press (psig) (X)	Input current (mA)	Output Press (psig) (Y)	Deviation in output (psig) (Y) - (X)
	Trial 1		Trial 2		
1.	3	6.5	3	6.4	0.1
2.	6	10.5	6	10.2	0.3
3.	9	14.5	9	14.3	0.2
4.	12	18.0	12	18.2	0.2
5.	15	20	15	20	0.0

Results and Discussion :-

From the graph, we can say that the output pressure was generally directly proportional to the current input with a few minor deviation. This indicates that the graph of P/I and I/P converter are mostly linear but not that accurate. However, there was some hysteresis, meaning that the output pressure was not always the same for a given input signal, depending on the direction of the change in the input signal.

The accuracy of the P/I and I/P converter was generally good with the measured output pressure being within the known value of the input signal. Overall, the results of the experiment was satisfactory. There were a few minor deviations from the ideal results. This deviation is because of the technical error with the experimental apparatus. Initially, the pressure output wasn't even changing after rotating the current knob. But after fixing some changes in apparatus, we got these results.

CONCLUSION :-

This experiment focused on studying the operation of P/I and I/P converters, where we allowed to observe and measure the relationship between input and output signals in both converter types.
We got to know the critical significance of proper caliberation in achieving accurate and reliable results. We also became aware of potential sources of error, ranging from non-linearity and hysteresis to environmental influence and manufacturing variations.
The relationship between current and pressure in the experiment on P/I and I/P converters is that the output pressure is directly proportional to the input current.
These currents are commonly used in industrial settings to regulate pressure in pipelines, tanks and reactors.

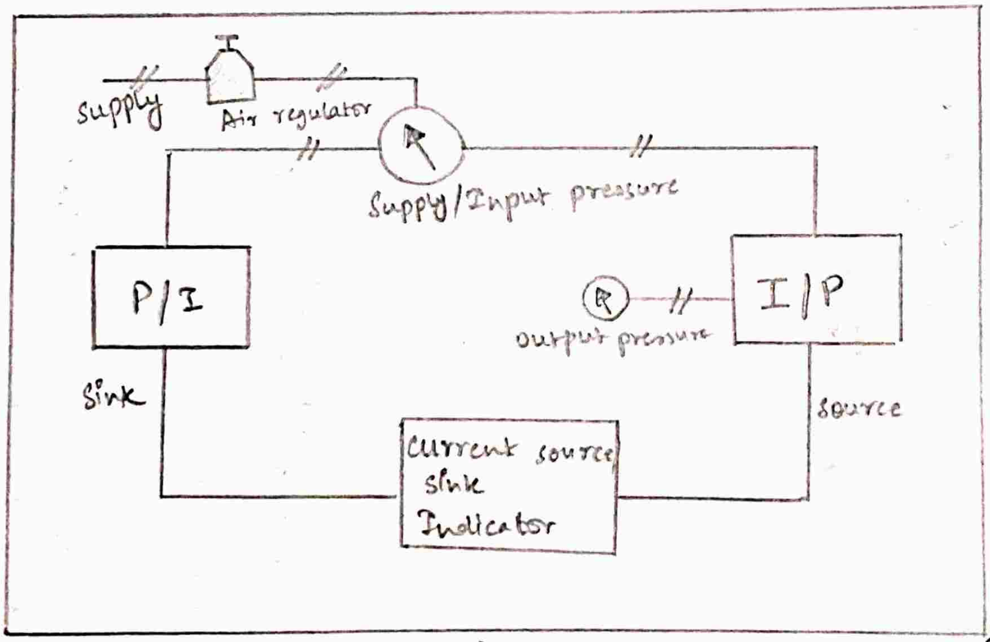

Fig:- P/I and I/P converter experimental setup

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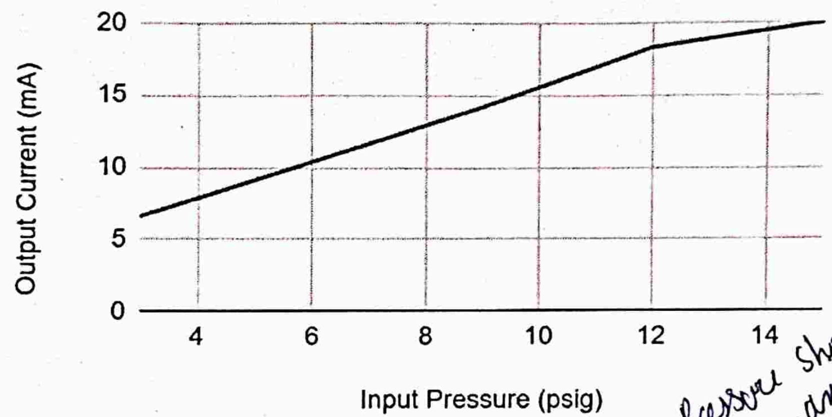
Hysteresis Not shown correctly

Magani
14/9/23

I/p-graph axis not cor

For I/P Converter

Input Pressure (psig) vs Output Current..

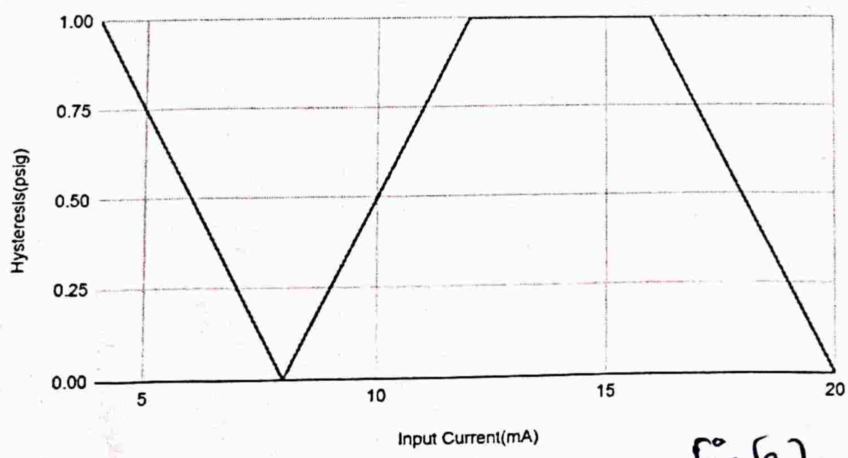


Pressure should by y-axis P is output

fig (1.)

HYSTERESIS PLOT

Hysteresis(psig) vs Input Current(mA)



Not the correct way to show hysteresis

fig.(2.)

For P/I Converter

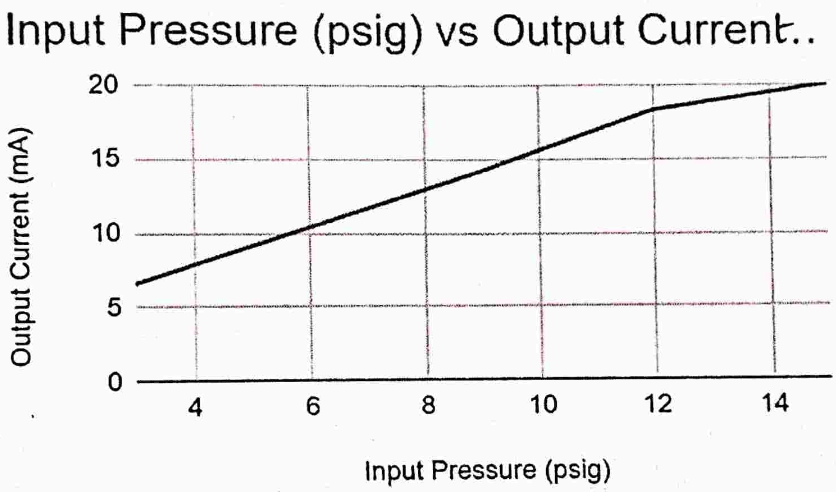
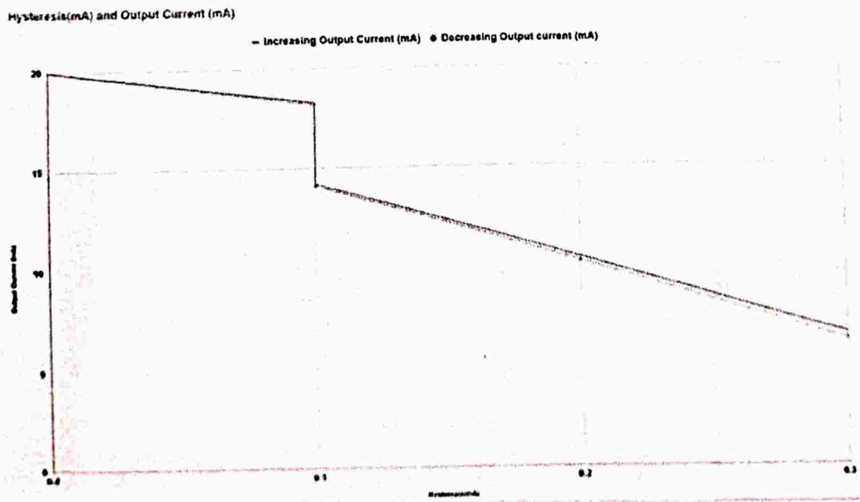


Fig. (3.)

HYSTERESIS PLOT



Hysteresis Not Shown Correctly.

Fig. (4.)