The University of Jordan

School of Engineering

Department of Chemical Engineering

Chemical Engineering Laboratory (4) (0905562)

Section no. (1)

Experiment no. (6)

Level Control

Short Report

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ABSTRACT

The main objectives to this experiment are to understand the working principle for the diaphragm pump, draw characteristic curve of the flow, to understand the effect of hysteresis on the level control, to represent the dynamic curve of the system using the proportional and proportional integral controller of the level control. The system is a rig consisting of a tank of water where the water level in a process vessel tank was used a PV to be controlled. The aim of the experiment was to control the water level in the process vessel tank by using the different control systems which were mentioned earlier. The on/off controller alternates between 2 different output which was completely switched on or completely switched off.

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RESULTS

- Steady State Characteristics of Final Control Element (Pump)

Table 1: Experimental Data for Pump Characteristics

Flow Rate (ml/min)	Voltage (V)
900.00	3.39
1000.00	3.42
1100.00	3.55
1200.00	3.65
1300.00	3.79
1400.00	4.04
1500.00	4.11
1600.00	4.19
1700.00	4.33
1800.00	4.61
1900.00	4.67
2000.00	4.88
2100.00	5.12
2200.00	5.4
2300.00	5.65
2400.00	6.01
2500.00	6.61
Gp (cm^3/V.min)	378.97

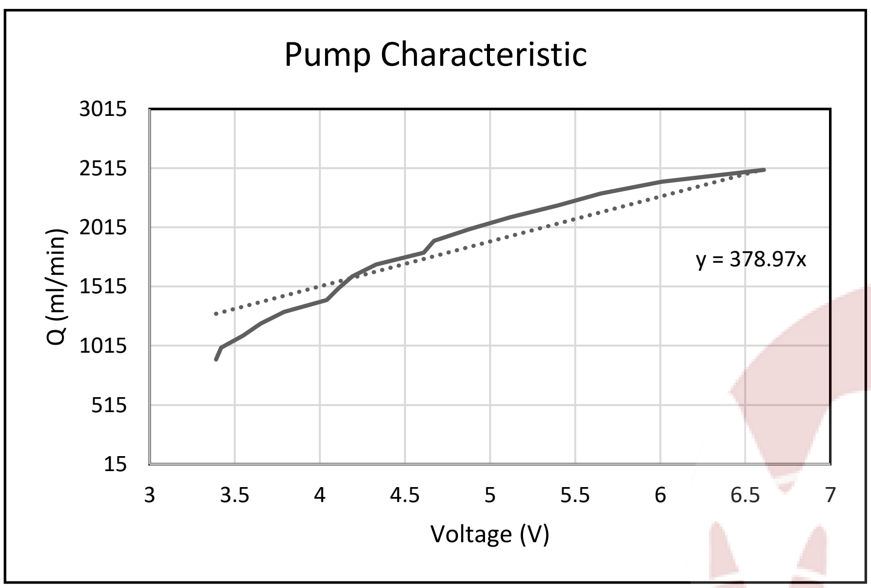

Figure 1: Flowrate versus Voltage

- Steady State Characteristics of Measuring Device (Level Sensor)

Table 2: Experimental Data for Level Control Characteristics

H_2(cm)	H_2(V)
28.5	10.05
27.00	8.87
26.00	7.67
25.00	6.79
24.00	6.01
23.00	5.4
22.00	4.94
21.00	4.53
20.00	4.17
19.00	3.88
18.00	3.67
17.00	3.46
16.00	3.29
15.00	3.14
14.00	3.01
13.00	2.89
12.00	2.77
11.00	2.6
10.00	2.44
9.00	2.33
8.00	2.25
7.00	2.19
6.00	2.16
5.00	2.11
4.00	2.02
3.00	1.91
Gd (V/cm)	0.2593

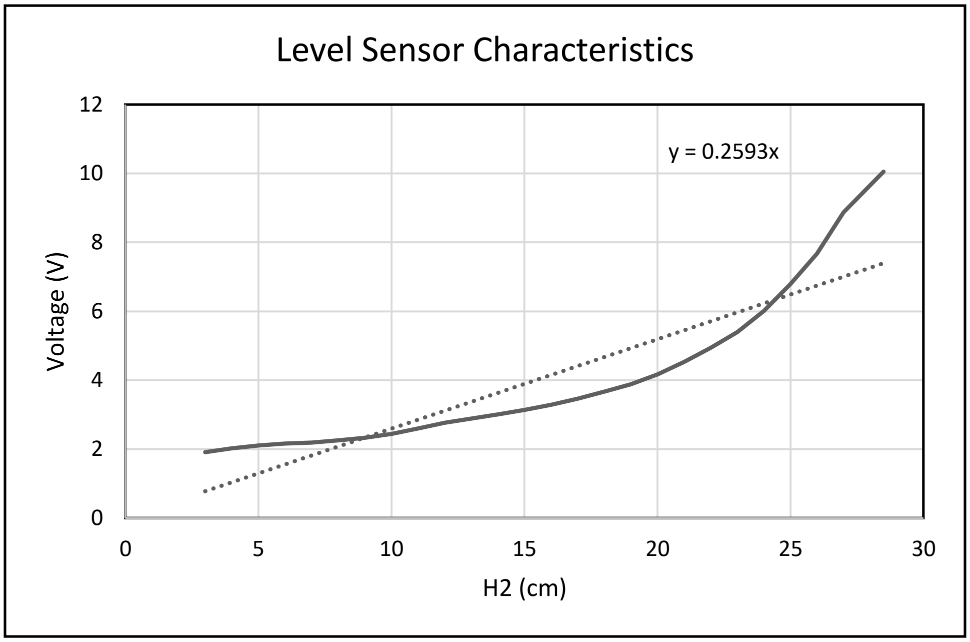

Figure 2: Voltage versus Fluid Level in Tank 2

- Dynamic Characteristics

Table 3: Steady State Conditions

Q (ml/min)	1500.00
H_{1S} (cm)	9.80
H_{2S} (cm)	6.60

Table 4: Given Data

H_3 (cm)	3.000
a_1 (cm^2)	0.708
a_2 (cm^2)	0.317
Cd_1,Cd_2	0.600
A (cm^2)	200.00
g (cm/s^2)	980.665

Table 5: Calculated Data

k_1 (cm^2/s)	5.262
k_2 (cm^2/s)	2.216
τ_1 (s^{-1})	17.025
τ_2 (s^{-1})	201.451
$H_{1s,th}$ (cm)	7.319
Error %	33.90%

→Transfer Function that relates the level in tank 1 with input flowrate

$$\frac{h_1(s)}{q_i(s)} = \frac{0.64 + 17.15s}{(17.03s + 1)(201.45s + 1)}$$

→Transfer Function that relates the level in tank 2 with input flowrate

$$\frac{h_2(s)}{q_i(s)} = \frac{0.45}{(17.03s + 1)(201.45s + 1)}$$

- Steady State Errors Using Proportional Controller

Table 6: Proportional Controller Experimental Errors

kp	10.000	5.000	3.000
Vs (V)	2.870	2.480	2.010
Q (ml/min)	1087.644	939.846	761.730
H_{2S} (cm)	11.068	9.564	7.752
Experimental Error %	34.89%	43.74%	54.40%

Table 7: Proportional Controller Experimental Data

H Set Point (cm)		17.00	
V Set Point (V)		4.4081	
Time (min)	Voltage (V)		
	kp=10	kp=5	kp=3
0.00	0.01	0.00	0.00
5.00	2.29	0.01	1.92
10.00	2.33	2.07	1.95
15.00	2.42	2.13	1.98
20.00	2.55	2.14	1.99
25.00	2.69	2.16	2.00
30.00	2.73	2.18	2.00
35.00	2.78	2.23	2.00
40.00	2.81	2.28	2.01
45.00	2.84	2.33	2.01
50.00	2.85	2.37	2.01
55.00	2.86	2.4	2.01
60.00	2.87	2.43	2.01
65.00	2.87	2.45	2.01
70.00	2.87	2.46	2.01
75.00	2.87	2.47	2.01
80.00	2.87	2.48	2.01
85.00	2.87	2.48	2.01
90.00	2.87	2.48	2.01

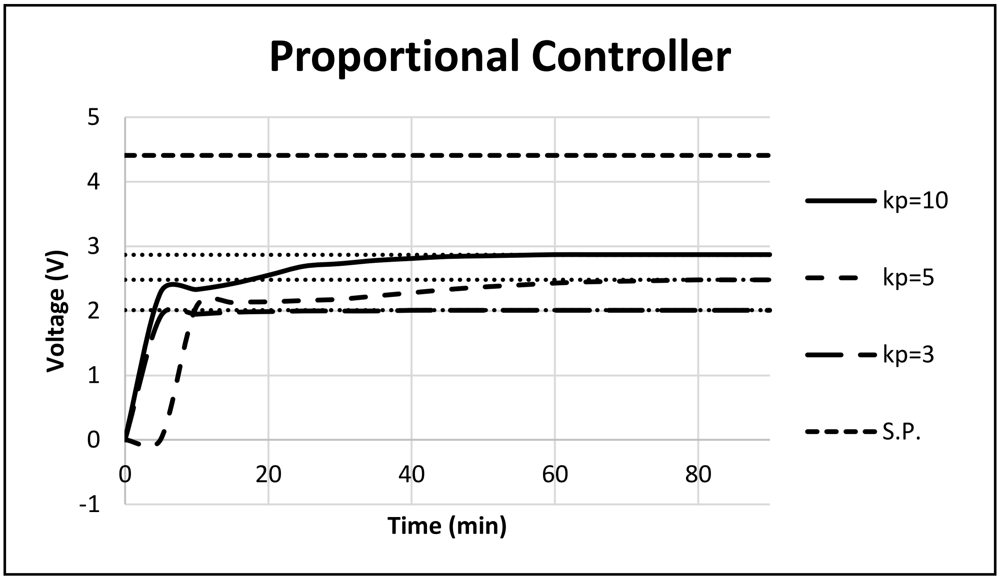

Figure 3: Voltage versus Time for P Controller

- Steady State Errors Using Proportional Plus Integral Controller

Table 8: Proportional Plus Integral Controller Experimental Errors

τ_i	1.00	0.50
Vs (V)	3.485	3.42
Q (ml/min)	1320.71	1296.08
H_{2S} (cm)	13.44	13.1894
Experimental Error %	21%	22.42%

Table 9: Proportional Plus Integral Controller Experimental Data

H Set Point (cm)		17
kp		10
Time (min)	Voltage (V)	
	τ_i=1	τ_i=0.5
0	0	0
0.5	2.97	2.78
1	3.82	3.79
1.5	3.86	3.42
2	3.64	3.41
2.5	3.51	3.42
3	3.49	3.42
3.5	3.49	3.42
4	3.48	3.42
4.5	3.48	3.42
5	3.48	3.42
5.5	3.49	3.42
6	3.48	3.42
6.5	3.48	3.42
7	3.48	3.42
7.5	3.49	3.42
8	3.48	3.42
8.5	3.48	3.42
9	3.48	3.42
9.5	3.49	3.42
10	3.48	3.42
10.5	3.48	3.42
11	3.48	3.42
11.5	3.48	3.42
12	3.49	3.42
12.5	3.48	3.42
13	3.49	3.42
13.5	3.48	3.42
14	3.48	3.42
14.5	3.49	3.42
15	3.49	3.42

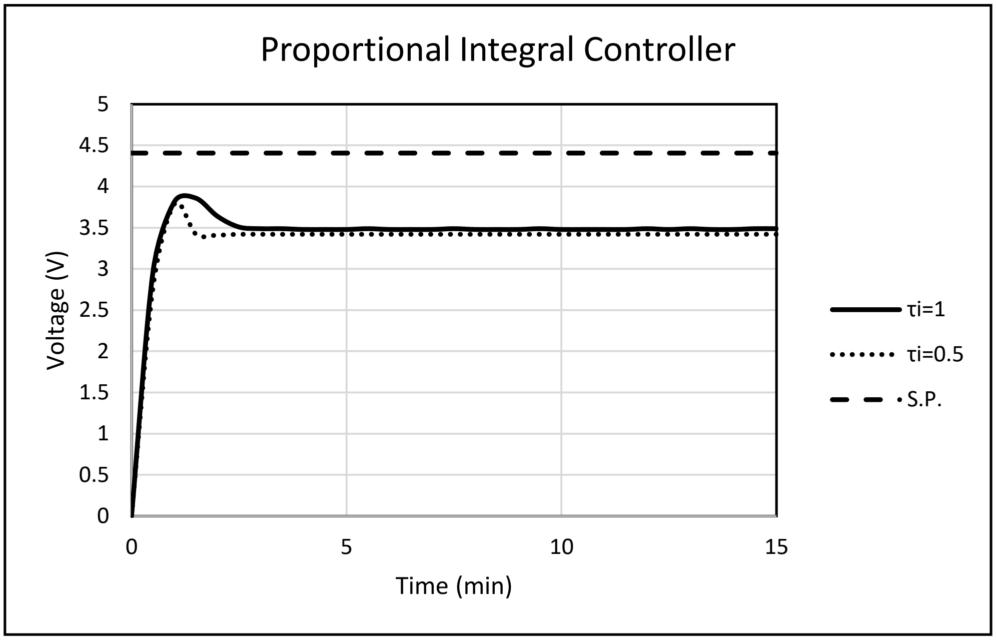

Figure 4: Voltage versus Time for PI Controller

DISCUSSION

The steady-state characteristic of the final control element, a pump, was investigated by plotting the flowrates versus voltage. The pump characteristic (Gp), representing the slope, was obtained, yielding a value of 378.97 cm^3/V.min, as shown in Figure 1.Similarly, the steady-state characteristic of the measuring device, a level sensor, was determined by plotting the voltage versus fluid level in the tank. The depth sensor characteristic (Gd), representing the slope, was found to be 0.2593 V/cm, as shown in Figure 2.

In order to study the dynamic characteristics of the system, the parameters ($cd_1a_1\sqrt{2g}\ a$) and ($cd_2a_2\sqrt{2g}$) were obtained to calculate k1, k2, τ_1, and τ_2. These parameters were crucial for analyzing the system's response to specific effects. The values of k1, k2, τ_1, and τ_2 were then compared at steady-state operating levels, and the steady-state level in tank 1 was calculated using an equation. However, a discrepancy was observed between the calculated steady-state level ($H_{1s,th}$) and the desired set point value of H1. The calculated steady-state level was determined to be 7.319 cm, resulting in an experimental error of 33.90%. The presence of external disturbances or influences, along with potential measurement errors or inaccuracies in determining the parameters ($cd_1a_1\sqrt{2g}\ a$) and ($cd_2a_2\sqrt{2g}$), could have contributed to the observed deviation from the set point value. Additionally, variations in fluid properties or uncertainties in the system model might have affected the system's response.

Moving to the design of proportional and proportional-integral controllers, the performance of a proportional controller was examined for different values of Kp (10, 5, and 3), with set points of H = 17 cm and V = 4.408 V. However, upon reaching a new steady state, a deviation from the set points was observed for the values of the level tank (H) and the voltage across the tank. This deviation occurred because a proportional controller alone cannot completely eliminate the offset. Increasing the gain of the controller can decrease the offset, but it cannot entirely remove it. Therefore, the values of the new steady state for the level tank and voltage deviated from their set points, as shown in Table 6 and Figure 3.

To improve control performance, proportional-integral (PI) controllers were introduced. The effect of the integral time τ_I was studied for values of 1.00 and 0.50 s^{-1}, while maintaining the same set points of H = 17.00 cm and V = 4.408 V. The results, presented in Table 8, demonstrated that the new steady-state values of the tank level and voltage were even closer to the set points compared to the proportional controller. This improvement was attributed to the integral part of the controller, which effectively eliminated the offset that the proportional part alone could not eliminate.

So, the experiment provided valuable insights into the steady-state and dynamic characteristics of the system. The proportional controller alone was insufficient in completely eliminating the offset, resulting in deviations from the set points. However, with the addition of the integral part in the proportional-integral controller, the offset was significantly reduced, leading to improved control performance. The gain of the controller and the integral time were found to be critical factors in achieving closer adherence to the set points.

CONCLUSION AND RECOMMENDATIONS

- ✓ The experiment focused on investigating the steady-state characteristics of a pump (final control element) and a level sensor (measuring device). Slopes representing the pump (Gp) and level sensor (Gd) were determined, providing essential insights into the behaviour of the system.
- ✓ Proportional controllers were examined with varying gain values, revealing their limitations in completely eliminating offset and resulting in deviations from set points during steady-state operation.
- ✓ Level and voltage are proportionate; a reduction in one causes a comparable decrease in the other.
- ✓ Introduction of proportional-integral (PI) controllers significantly improved control performance. The integral part effectively reduced the offset, leading to new steady-state values much closer to the set points compared to the proportional controller.
- ✓ The experiment highlighted the critical role of controller gain and integral time in achieving optimal control performance. The limitations of a proportional controller were evident, emphasizing the need for incorporating integral components in control systems to enhance accuracy and adherence to set points.
- ✓ In control systems, stability, precision, and response time are necessary.

REFERENCES

1) Chemical Engineering Laboratory (4) Manual Sheet. (2022). 1st ed. University of Jordan School of Engineering Department of Chemical Engineering.

APPENDICES

I. Sample Of Calculations

- Pump Characteristics Gp

By plotting flowrate versus voltage and linearizing data, the following equation is obtained:

$$y = 378.97x$$

$Gp = slope = 378.97 \frac{cm^3}{V.min}$

- Depth Sensor Characteristics Gd

By plotting voltage versus fluid level in tank 2 and linearizing data, the following equation is obtained:

$y = 0.2593x$

$Gd = slope = 0.2593\ V/cm$

- Cross Sectional Area of Tank

$A = width * length = 10 * 20 = 200\ cm^2$

- Cross Sectional Area of Orifice 1&2

$$a_1 = \frac{\pi D^2}{4} = \frac{3.14 * (0.95)^2}{4} = 0.708\ cm^2$$

$$a_2 = \frac{\pi D^2}{4} = \frac{3.14 * (0.635)^2}{4} = 0.32\ cm^2$$

- k1 & k2 Calculation

Given: $cd_1 = cd_2 = 0.6$, $H_3 = 3\ cm$, $H_{1s} = 9.8\ cm$, $H_{2s} = 6.6\ cm$, $g = 980.665\ cm/s^2$

$$k_1 = \frac{cd_1 a_1 \sqrt{2g}}{2\sqrt{H_{1s} - H_{2s}}} = \frac{0.6 * 0.708\sqrt{2 * 980.665}}{2\sqrt{9.8 - 6.6}} = 5.26\ cm^2/s$$

$$k_2 = \frac{cd_2 a_2 \sqrt{2g}}{2\sqrt{H_{2s} - H_3}} = \frac{0.6 * 0.32\sqrt{2 * 980.665}}{2\sqrt{6.6 - 3}} = 2.22\ cm^2/s$$

- Time Constants τ_1 & τ_2

$$\tau_1\tau_2 = \frac{A^2}{k_1k_2} \quad , \quad \tau_1 + \tau_2 = \frac{A(2k_1 + k_2)}{k_1k_2}$$

$$\tau_1\tau_2 = \frac{(200)^2}{5.26 * 2.22} \text{ ------------------------ } 1$$

$$\tau_1 + \tau_2 = \frac{200(5.26 + 2.22)}{5.26 * 2.22} \text{ ---------------------- } 2$$

By solving equations 1 & 2 → $\tau_1 = 17.025\ s^{-1}$, $\tau_2 = 201.45\ s^{-1}$

- Transfer Function That Relates Level of Fluid In Tank (1) With Input Flowrate

$$\frac{h_1(s)}{q_i(s)} = \frac{\frac{k_1 + k_2}{k_1k_2} + \frac{A}{k_1k_2}s}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

$$\frac{h_1(s)}{q_i(s)} = \frac{0.64 + 17.15s}{(17.03s + 1)(201.45s + 1)}$$

- Transfer Function That Relates Level of Fluid In Tank (2) With Input Flowrate

$$\frac{h_2(s)}{q_i(s)} = \frac{1/k_2}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

$$\frac{h_2(s)}{q_i(s)} = \frac{0.45}{(17.03s + 1)(201.45s + 1)}$$

- Theoretical Steady State Level in Tank 1

$$H_{1s,th} = H_{2s}(1 + (a_2/a_1)^2) - H_3(a_2/a_1)^2$$

$$H_{1s,th} = 6.6\left(1 + \left(\frac{0.32}{0.702}\right)^2\right) - 3\left(\frac{0.32}{0.702}\right)^2 = 7.32\ cm$$

$$Error\% = \left|\frac{H_{1s.th} - H_{1s}}{H_{1s.th}}\right| * 100\% = \left|\frac{7.32 - 9.8}{7.32}\right| * 100\% = 33.9\%$$

- Proportional Controller for kp=10

$H_{sp} = 17\ cm$
$V_s = 2.87\ Volt$
$Q = Gp * V_s = 378.97 * 2.87 = 1087.644\ ml/min$
$H_{2s} = \frac{V_s}{Gd} = \frac{2.87}{0.259} = 11.068\ cm$
$Experimental\ Error\ \% = \left|\frac{H_{sp} - H_{2s}}{H_{sp}}\right| * 100\% = \left|\frac{17 - 11.068}{17}\right| * 100\% = 34.89\%$

- Integral and Proportional Controller for τ_i=1

$H_{sp} = 17\ cm$
$V_s = 3.485\ Volt$
$Q = Gp * V_s = 378.97 * 3.485 = 1320.71\ ml/min$
$H_{2s} = \frac{V_s}{Gd} = \frac{3.485}{0.259} = 13.44\ cm$
$Experimental\ Error\ \% = \left|\frac{H_{sp} - H_{2s}}{H_{sp}}\right| * 100\% = \left|\frac{17 - 13.44}{17}\right| * 100\% = 21\%$

II. Date Sheet

Experiment (6)

Level Control Data Sheet

Measuring Device calibration:

H_2 (cm)	H_2 (V)
28.5	10.05
27	8.87
26	7.67
25	6.79
24	6.01
23	5.4
22	4.94
21	4.53
20	4.17
19	3.88
18	3.67
17	3.46
16	3.29
15	3.14
14	3.01
13	2.89
12	2.77
11	2.6
10	2.44
9	2.33
8	2.25
7	2.19
6	2.16
5	2.11
4	2.02
3	1.91

Pump calibration:

Flow rate (ml/min)	Voltage (V)
900	3.39
1000	3.42
1100	3.55
1200	3.65
1300	3.79
1400	4.04
1500	4.11
1600	4.19
1700	4.33
1800	4.61
1900	4.67
2000	4.88
2100	5.12
2200	5.4
2300	5.65
2400	6.01
2500	6.61

Steady state condition

Q (ml/min)	1500
H_{1s}(cm)	9.8
H_{2s}(cm)	6.6

Proportional Controller:

Set point= 17cm			
Time	K_p =10	K_p =5	K_p =3
0	0.01	0	0
5	2.29	0.01	1.92
10	2.33	2.07	1.95
15	2.42	2.13	1.98
20	2.55	2.14	1.99
25	2.69	2.16	2
30	2.73	2.18	2
35	2.78	2.23	2
40	2.81	2.28	2.01
45	2.84	2.33	2.01
50	2.85	2.37	2.01
55	2.86	2.4	
60	2.87	2.43	
65	2.87	2.45	
70	2.87	2.46	
		2.47	
		2.48	
		2.48	
		2.48	

Proportional and Integral Controller:

Set point= 17cm			
K_p =10			
Time	τ_i = 1	τ_i = 0.5	τ_i =
0	0	0	
0.5	2.97	2.78	
1	3.82	3.79	
1.5	3.86	3.42	
2	3.64	3.41	
2.5	3.51	3.42	
3	3.49	3.42	
3.5	3.49	3.42	
4	3.48	3.42	
4.5	3.48	3.42	
5	3.48	3.42	
5.5	3.49	3.42	
6	3.48	3.42	
6.5	3.48	3.42	
7	3.48	3.42	
7.5	3.49	3.42	
8	3.48	3.42	
8.5	3.48	3.42	
9	3.48	3.42	
9.5	3.49	3.42	
10	3.48	3.42	
10.5	3.48	3.42	
11	3.48	3.42	
11.5	3.48	3.42	
12	3.49	3.42	
12.5	3.48	3.42	
13	3.49	3.42	
13.5	3.48	3.42	
14	3.48	3.42	
14.5	3.49	3.42	
15	3.49	3.42	