Group #2

The University of Jordan
School of Engineering
and Technology

87/100

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 1: Continuous Stirred Tank Reactor

Report Type: Short Report

Done by:

Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

Submission Date:3/11/2021

Abstract

The experiment objective is to determine the kinetics and reaction rate constant of the essentially irreversible reaction between ethyl acetate and sodium hydroxide by the capacity flow method and to measure the residence time density function of the effluent stream.

In this experiment the reaction of Sodium Hydroxide with Ethyl acetate in continuous stirred tank reactor or commonly known as CSTR, is obtained with different reactants flow rates in order to investigate the rate of reaction order, rate constant and the reaction model, response of rate if reaction with final concentration of sodium hydroxide is obtained from the plot.

Finally, Titration of NaOH and $CH_3COOC_2H_5$ is done in order to ensure their concentrations.

Result

Table 1:Data

Titrants	
Conc.of HCl (M)	0.03
Conc.of NaOH (M)	0.03
Reactants	
Vol. of NaOH sample (ml)	10
Vol. of HCl need for titration (ml)	11
Vol. of ethyl acetate sample (ml)	10
Vol. of NaOH need (ml)	30
Vol. of HCl need for titration (ml)	16.5
Vol. of reacted NaOH	13.5
initial conc. of reactant ethyl acetate (M)	0.0405
initial conc. of NaOH (M)	0.033

Table 2:Reaction Information

Run	**Flow rate of ethyl acetate(ml/s)**	**Flow rate of NaOH(ml/s)**	**Vol. flow rate of Reactant(L/min)**	**Flow rate of ethyl acetate(mol/s)**	**Flow rate of NaOH(mol/s)**	**τ (min)**	**Residence Time(min)**
1	7	7	0.84	0.0002835	0.000231	3.214	16.071
2	8	6	0.84	0.000324	0.000198	3.214	16.071
3	6	8	0.84	0.000243	0.000264	3.214	16.071

Table 3:Data from Titration

Run	**Sample 1: Vol. of NaOH (ml)**	**Sample 2: Vol. of NaOH (ml)**	**Avg. Volume of NaOH (ml)**	**Volume of HCl (left) (ml)**	**Volume of excess sample of HCl (ml)**	**Volume of reacted HCl (ml)**	**Volume of sample from reactor (ml)**	**Final conc. of NaOH (M)**
1	8	8	8	8	15	7	10	0.021
2	8.4	8.6	8.5	8.5	15	6.5	10	0.0195
3	10	10.1	10.05	10.5	15	4.5	10	0.0135

Table 4:Reaction Kinetics

Run	**X**	**Rate of reaction (r_{NaOH})**	$\theta_{CH_3COOC_2H_5}$	**k**	**Temp. (°C)**
1	0.36	3.11E-05	1.227	0.05198	20
2	0.41	3.00E-05	1.636	0.03799	20
3	0.59	5.78E-05	0.920	0.39355	20

Discussion

When determinant the concentration of reactants with time in experiment you can to investigate the reaction kinetics, and reaction rate. In this experiment we do a reaction between Ethyl Acetate and NaOH and this is an irreversible reaction, also its takes a long time to achieve high conversion.

$$NaOH + CH_3COOC_2H_5 \rightarrow CH_3COONa + C_2H_5OH$$

The first part in this experiment it's to check the Concentration of a feed tank is if it equals to 0.04M. we take NaOH sample from a feed tank and is titrated with 0.035M from HCL and use phenolphthalein indicator. then take Ethyl Acetate sample also from freed tank and is mixed with excess NaOH, and is left to set overnight before titrating against 0.03M HCL.

Then for a set of flow rates we take a sample from CSRT tank at steady state condition to determination the concentration where excess HCL is added to each sample, and then is titrated against standardized NaOH, using phenolphthalein as an indicator.

the second part, the reaction is assumed to be elementary: $-r_a = k\ C_a\ C_b$. Due to changing the reactants flow rates, rat of reaction and rate constant changes. NaOH is supplied to the reaction as limiting reactant. The reaction order is second order.

The plot of reaction rate with NaOH concentration is polynomial with order = 2. ← where is this plot

The reason behind the change in molarity of Ethyl Acetate can be a result of dissolution of this weak acid with time and being affected by the ambient conditions since the feed tank isn't completely insulated.

The value of conversion of NaOH was discovered at various flow rate its:

run	conversion
1	0.36
2	0.41
3	0.59

the value of K was discover is :

run	K
1	0.05198
2	0.03799
3	0.39355

Conclusion and Recommendation

Conclusion:

7.

The experiment is considered to be successfully done since all the objectives is achieved, the reaction rate equation (n, K) is determined

In CSTR experiment, the order of reaction is second order reaction. For the experiment the concentration of reactants must be kept constant and the samples must be taken when residence time spent accurately.

Recommendations:

There are several recommendations can be made to improve the experiment for a better result:

1- Make sure reactor does not have any leaks and valve closed and opened as needed, controlled the valve carefully and slowly when adjusting the flow rate

2- Make sure the flow rates of NaOH and ethyl acetate are stable during each run of the experiment.

3- We may Repeat the titrations for two or three times because a lot of error comes from titration.

Appendix

→ Sample of calculation for first run:

- **Initial concentration of NaOH:**

$M_{NaOH} V_{NaOH} = M_{HCl} V_{HCl}$

$M_{NaOH} * 10 = 0.03 * 11$

$M_{NaOH} = 0.033M$ ✓

- **Initial concentration of $CH_3COOC_2H_5$:**

Volume of excess NaOH:

$M_{NaOH} V_{NaOH} = M_{HCl} V_{HCl}$

$0.03 * V_{NaOH(excess)} = 0.03 * 16.5$

$V_{NaOH(excess)} = 16.5\ ml$

Volume of reacted NaOH:

$V_{NaOH} = 30 - 16.5 = 13.5\ ml$ ✓

$M_{NaOH} V_{NaOH} = M_{CH_3COOC_2H_5} V_{CH_3COOC_2H_5}$

$0.03 * 13.5 = M_{CH_3COOC_2H_5} * 10$

$M_{CH_3COOC_2H_5} = 0.0405M$ ✓

- **Final concentration of NaOH:**

$M_{NaOH} V_{NaOH} = M_{HCl} V_{HCl}$

$0.03 * 8 = 0.03 * V_{HCl}$

$V_{HCl(Excess)} = 8\ ml$

Volume of HCl reacted with NaOH:

$V_{HCl} = 15 - 8 = 7ml$ ✓

Final concentration of NaOH:

$M_{NaOH} V_{NaOH} = M_{HCl} V_{HCl}$

$M_{NaOH} * 10 = .03 * 7$

$M_{NaOH} = .021M$ ✓

Cn

- **Conversion X:**

$$X = \frac{M_{NaOH_0} - M_{NaOH_{final}}}{M_{NaOH_0}}$$

$$X = \frac{0.033 - 0.021}{0.033} = 0.364$$ ✓

- **Initial molar Flow rate:**

$$F_{NaOH} = \frac{M_{NaOH} * V'}{1000} = \frac{0.033 * 7}{1000} = 0.000321\, mol/s$$

$$F_{CH_3COOC_2H_5} = \frac{M_{CH_3COOC_2H_5} * V'}{1000} = \frac{0.0405 * 7}{1000} = 0.0002835\, mol/s$$

- **Rate constant:**

$$NaOH + CH_3COOC_2H_5 \rightarrow CH_3COONa + C_2H_5OH$$

$$-r_{NaOH} = KM_{NaOH}M_{CH_3COOC_2H_5}$$

$$M_{NaOH} = M_{NaOH_0}(1 - x)$$

$$M_{CH_3COOC_2H_5} = M_{NaOH_0}(\theta_{CH_3COOC_2H_5} - x)$$

$$-r_{NaOH} = \frac{xF_{NaOH}}{V_{reactor}} = \frac{0.363 * 0.000321}{2.7} = 3.11 * 10^{-5}\, mol/L.s$$

$$\theta_{CH_3COOC_2H_5} = \frac{F_{CH_3COOC_2H_5}}{F_{NaOH}} = \frac{0.0002835}{0.000321} = 1.227$$

$$K = \frac{-r_{NaOH}}{M_{NaOH_0}{}^2(1 - x)(\theta_{CH_3COOC_2H_5} - x)}$$

$$= \frac{3.11 * 10^{-5}}{0.033^2 * (1 - 0.363) - (1.227 - 0.363)} = 0.05198\, L.s/mol$$

- **Preparation of the feed solutions:**

NaOH solution:

NaOH is solid materials

$M_{NaOH} = 0.04\ mol/L$

Volume=40L

Mwt=40 g/mol

$$0.04\frac{mol}{L} * 40L * 40\frac{g}{mol} = 46g \text{ we need from } NaOH$$ ✓

Ethyl acetate solution

M=0.04 mol/L

Volume=40 L

Mwt=88 g/mol

Density=0.9 g/ml

$$0.04\frac{mol}{L} * 40L * 88\frac{g}{mol} * \frac{ml}{0.9g} = 156.4\ ml\ we\ need\ from\ ethyl\ acetate$$

Continuous Stirred Tank Reactor's data sheet

Titrants:	
Conc. of HCL	0.03 M
Conc. of NaOH	0.03 M

Reactants:	
Volume of NaOH sample	10 mL
Volume of HCl needed for titration	11 mL
Volume of ethyl acetate sample	10 mL
Volume of NaOH added	30 ml
Volume of HCl needed for titration	16.5 mL

Item	**Run 1**	**Run 2**	**Run 3**
Flow rate of ethyl acetate	7 cm^3/se	8 cm^3/sec	6 cm^3/sec
Flow rate of sodium hydroxide	7 cm^3/sec	6 cm^3/sec	8 cm^3/sec
Residence time	3.217 min	3.217 min	3.217 min
Sample 1: Volume of NaOH	8 ml	8.4 mL	10 mL
Sample 2: Volume of NaOH	8 mL	8.6 mL	10.1 mL
Sample 3: Volume of NaOH			
Temperature	20 °C	20 °C	20 °C

Rula Mustafa

27/10/2021

الادباء

The University of Jordan
School of Engineering
and Technology

85/100

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 2: Temperature Measurement

Report Type: Short Report

Done By:

Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

Submission Date:1/12/2021

Abstract

In temperature measurement experiment, different methods of measuring temperature are applied in order to compare their efficiency, sensitivity, and accuracy. Perltier thermo _ electric effect and seebeck effect is studied due to specific connections, voltage calibration using direct measure compared with theoretical data, effect of using intermediate metal in connections and the purpose of using parallel and series connections.

Result

Part1: The temperature of the water by using Glass thermometer, Vapor pressure, Bi-metallic expansion device, Thermistor &Thermocouple.

Table 1:Readings for different measuring device for water at boiling point

Measuring device	Temperature (°C)	Explanation
Glass thermometer	97	The temperature read is accurate and fast
Vapor pressure	96	The vapor pressure and bi-metallic response more slowly Bi than glass thermometer and read inaccurately.
Bi-metallic	98	
Thermistor	98.5	Temperature reading is faster than glass thermometer; Reading is more accurate than bi-metallic and vapour pressure
Thermocouple	96.6	Even though the reading is less accurate than thermistor, it is the fastest device in temperature reading.

Part2: The response of each temperature measuring device as temperature change with time

Table 2:Measuring device response

Time(min)	Glass thermometer	Thermocouple	Thermistor	Vapor pressure	Bi-metallic
0	17	15.5	17.4	16	17
1	19	16.6	18.3	16	18
2	21	19.1	20.6	16	18
3	22	20.4	23.9	16	18
4	26	23.5	26.8	16	19
5	30	27.3	30.6	20	22
6	33	30.6	34.5	22	26
7	37	34	37.6	25	30
8	40	37.5	40.9	30	32
9	44	40.7	44.7	32	38
10	47	44.2	48.2	34	40
11	51	47.6	51.2	39	43
12	54	50.9	54.6	40	44
13	57	53.8	57.6	46	50
14	60	56.8	60.5	48	52
15	64	60.1	64	52	56
16	66	63.1	67	54	60
17	68	65.9	69.9	58	62.
18	71	68.7	72.7	60	66
19	73	71.2	74.8	62	68
20	75	74.1	77.3	66	72
21	78	76.4	79.4	68	74

22	80	78.7	81.7	71	78
23	82	80.9	84.2	74	80
24	84	82.3	86.5	76	82
25	86	85.9	88.4	80	84
26	88	88.2	90.7	82	86
27	90	90.1	92.4	82	88
28	92	90.5	94.6	86	90
29	94	93.3	95.3	88	92
30	95	94.9	97.3	90	95
31	96	96.1	98	92	96
32	96	96.3	98.3	94	96
33	97	96.4	98.4	96	98
34	97	96.5	98.4	96	98
35	97	96.6	98.5	96	98

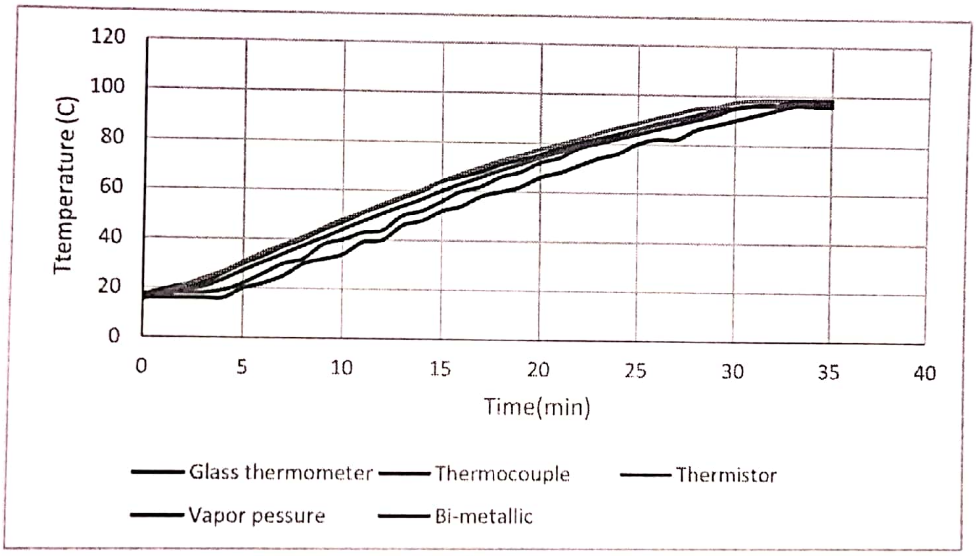


Figure 1:Measuring device response as temp. change with time

Part 3: Readings of millivolt

I. Peltier thermo-electric

Ambient temperature=16 °C

Table 3:Voltage reading with temperature

Time(min)	MILIVOLT	volt/40
0	-5.7	-0.143
1	-3.8	-0.095
2	0.5	0.013
3	6.7	0.168
4	13.4	0.335
5	18.6	0.465
6	24.3	0.608
7	28.8	0.720
8	34.1	0.853
9	39.5	0.988
10	44.6	1.115
11	50	1.250
12	54.5	1.363
13	59.3	1.483
14	64.4	1.610
15	69.7	1.743

16	75.2	1.880
17	79.3	1.983
18	83.6	2.090
19	87.6	2.190
20	92.3	2.308
21	96.1	2.403
22	99.3	2.483
23	103.4	2.585
24	107.4	2.685
25	110.1	2.753
26	114.3	2.858
27	142.3	3.558
28	146.1	3.653
29	151	3.775
30	171.3	4.283
31	175.5	4.388
32	176	4.400
33	173.6	4.340
34	173.8	4.345
35	174.5	4.363

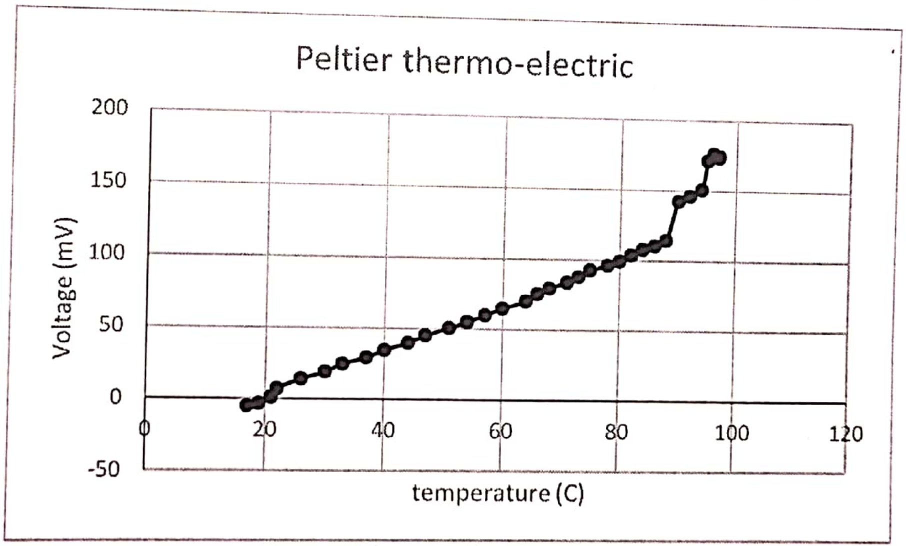


Figure 2:Voltage reading with temperature

➔ If the temperature reading below ambient temperature, voltage reading will be negative

II. Seebeck effect

	Voltage	Volt/40
Both thermocouple in cold water	0	0
Thermocouple (1) in cold and (2) in hot	160	4
Thermocouple (2) in cold and (1) in hot	-160	-4

➔ If tow thermocouple put in hot or cold water (same container) the reading of millivolt will be zero because there is no temperature gradient.

➔ When we switch between thermocouple the voltage sign reversed.

Part 4: Calibration of type k thermocouple

Table 4:comparing between voltage from table and from measuring device

Type k Thermocouple reading °C	Voltage (Experimental)	Voltage Tabulated
15.5	-0.143	0.617
16.6	-0.095	0.661
19.1	0.013	0.758
20.4	0.168	0.814
23.5	0.335	0.9395
27.3	0.465	1.093
30.6	0.608	1.228
34	0.720	1.366
37.5	0.853	1.5095
40.7	0.988	1.6407
44.2	1.115	1.7842
47.6	1.250	1.9242
50.9	1.363	2.06
53.8	1.483	2.1798
56.8	1.610	2.304
60.1	1.743	2.436
63.1	1.880	2.561
65.9	1.983	2.681

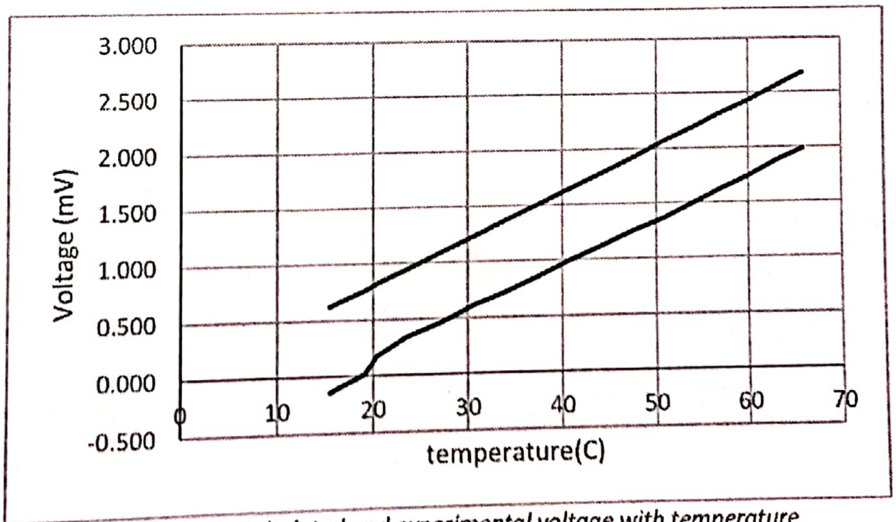


Figure 3: tabulated and experimental voltage with temperature

Part 5: The effect of intermediate metals and intermediate temperature on reading of millivolt

Intermediate metal:

I. Voltage for the junction without intermediate metal: the reading of millivolt didn't change between hot water and ice for three junctions.

II. Voltage for the junction with intermediate metal: the reading of millivolt in hot water different from reading in ice for junction B because of resistance.

Intermediate temperature:

The intermediate is hand. The reading of millivolt when thermocouple put in hot water and ice is equal to the summation of first reading (thermocouple between hand and ice) and second reading (thermocouple between hot water and hand).

	Voltage
$E_{hot} - E_{ice}$	160
$E_{hot} - E_{hand}$	97.7
$E_{hand} - E_{ice}$	-62.3

97.7+62.3=160

Part 6: parallel and series connection

A. Parallel connection

Table 5:Temp. for cold, tap and hot when depress individual switch and when depressing them at the same time

Temp by depress switch#1(cold)	7.6
Temp by depress switch#2(tap)	23
Temp by depress switch#3(hot)	98.2
Temp by depress switch#1+2	15.8
Temp by depress switch#1+2+3	38.6

Averag temp.=$\frac{7.6+23}{2} = 15.3$ ✓

compare

Averag temp.=$\frac{7.6+23+98.2}{3} = 42$ ✓

- As we see from above table when depressing switch at the same time the value of temperature is equal to the average value when depress switch individually.

B. Series connection

The reading will amplify by number of thermocouples that inside water in our experiment it was 2.

✓

Discussion

1. Part one of experiment shows:
    - comparison of the accuracy of each device with reference to the original boiling point 100c.
    - The most accurate device is the thermistor since it has the closest value to the original boiling point.
    - The least accurate device is vapor pressure since it has the farthest value to the original boiling point.
2. Part two of experiment shows study of response for different measuring device uses:

According to precision

- Thermistor > glass thermometer >thermocouple

3. Part three of experiment shows the Peltier and Seebeck effect where:
    - When the temperature is less than the ambient temperature the millivolt reading will be in negative and this is known as Peltier effect.
    - From seebeck effect we see that when the two couples are in the same place the reading of millivolt will be zero or almost zero since there is not any temperature gradient.
    - When the thermocouple has each part in cold and hot water, there will be a temperature gradient so the millivolt reading will not be zero, it will have a value and the negative sign due to the direction.
4. Part four of the experiment studies the Voltage calibration of different thermometer types using water-ice reference:
    - A comparison between tabulated data of millivolt reading with experimental data of millivolt
5. Part five of the experiment shows the effect of intermediate metal and intermediate temperature:
    - Reading of millivolt changed after adding an intermediate metal which means that this metal is different than the original metal used in thermocouple.
    - When removing any of the thermocouples from hot or cold water to hand the reading of millivolt will be affected. If we add the value of millivolt for cold water and hand, to the value of millivolt of hot water and hand, the final value will be the millivolt value for hot and cold.
6. Part six of the experiment studies the effect of parallel and series connection in thermocouples:
    - parallel connecting, give average the millivolt reading while connecting in series, amplified reading by the number of

Conclusion

This work has discussed the temperature measurement and calibration procedure for various sensors, and their response and characteristics are fully observed during the experiment.

As we see the most accurate device is thermistor, connecting thermocouple in parallel will give an average reading, while by connecting it in series the reading will not change.

The source of error in this experiment come over reading the scale which is human factor and there is technical issue from the measuring devices.

ambification
Thermall Dev
couple

Temperature Measurement

Part # 1

	Temperature (°C)	
Glass thermometer	97	→ 3
Vapor pressure	96	→ 5
Bi-metallic	98	→ 2
Platinum resistance	—	
Thermistor	98.5	→ 1
Thermocouple	96.6	→ 4

Part # 2

① ①

Time (min)	Temperature (°C) Glass thermometer	Thermocoup	Thermo STat	Vaper P	bi-metali
0	17	15.5	17.4	16	17
1	19	16.6	18.3	16	18
2	21	[illegible]	20.6	16	18
3	22	20.4	23.9	16	18
4	26	23.5	26.8	16	19
5	30	27.3	30.6	20	22
6	33	30.6	34.5	22	26
7	37	34	37.6	25	30
8	40	37.5	40.9	30	32
9	44	40.7	44.7	32	38
10	47	44.2	48.2	34	40
11	51	47.6	51.2	39	43
12	54	50.9	54.6	40	44
13	57	53.8	57.6	46	50
14	60	56.8	60.5	48	52
15	64	60.1	64	52	56
16	66	63.1	67	54	60
17	68	65.9	69.9	58	62
18	71	68.7	72.7	60	66
19	73	71.2	74.8	62	68
20	75	74.1	77.3	66	72
21	78	76.4	79.4	68	74
22	80	78.7	81.7	71	78
23	82	80.9	84.2	74	80
24	84	80.3	86.5	76	82
25	86	85.9	88.4	80	84
26	88	88.2	90.7	82	86
27	90	90.1	92.4	82	88
28	92	90.5	94.6	86	90
	94	93.3	95.8	88	92

rt # 5

Intermediate metal:

Voltage for the junction without intermediate metal:

	Voltage
Junction **A** in hot water	160
Junction **B** in hot water	160
Junction **C** in hot water	160
Junction **A** in ice	160
Junction **B** in ice	160
Junction **C** in ice	160

Voltage for the junction with intermediate metal:

	Voltage
Junction **B** in hot water	-120
Junction **B'** in ice	-133.6

Intermediate Temperature:

	Voltage
$E_{hot} - E_{ice}$	160
$E_{hot} - E_{hand}$	97.7
$E_{hand} - E_{ice}$	- 62.3

10

Part # 6

→ avg reading

Parallel connection:

cold	Temp by depress switch # 1	7.6
Tap	Temp by depress switch # 2	23
hot	Temp by depress switch # 3	98.2
	Temp by depress switch # 1+2	15.8
	Temp by depress switch # 1+2+3	38.6

Series connection:

Voltage =	2.8.4 mV
1	4.2

24/11/221

art # 3

a- Peltier thermo-electric:

جداول

Ambient temperature: 16 °C

Time (min)	~~Temperature (°C)~~ mV ~~Glass thermometer~~ Thermocouple	time (min)	(mV)
0	~~-057~~ -5.7	21	96.1
1	- 3.8	22	99.3
2	0.5	23	103.4
3	6.7	24	67.4
4	13.4	25	110.1
5	18.6	26	114.3
6	24.3	27	142.3
7	28.8	28	146.1
8	34.1	29	151.0
9	39.5	30	171.3
10	44.6	31	175.5
11	50.0	32	176.0
12	54.5	33	173.6
13	59.3	34	173.8
14	64.4	35	174.5
15	69.7	36	
16	75.2	37	
17	79.3	38	
18	83.6	39	
19	87.6	40	
20	92.3	41	

b- Seebeck effect:

	Voltage
Both thermocouples in cold water	0
Thermocoulpe (1) in cold and (2) in hot	160.0
Thermocoulpe (2) in cold and (1) in hot	- 160.0

الأربعاء

Group # 2

The University of Jordan
School of Engineering and Technology

60
100

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 4: Tubular Flow Reaction

Report Type: Short Report

Done By:
Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

Submission Date:15/12/2021

Abstract

In tubular reactor experiment, rate of reaction order is estimated as a function of concentration, also rate constant is estimated as a function of temperature from Arrhenius equation, K values is graphically estimated or calculated by the integration of residence time equation, reaction order is second order reaction

✓

Result & Discussion

Tabulated result

run #	1	2	3
concentration of ethyl acetate	0.06	0.06	0.06
concentration of NaoH (CA₀)	0.06	0.06	0.06
flowrate of ethyl acetate	50	60	70
flow rate of NaoH	50	60	70
residence time (τ)	20	16.5	14.3
current concentration of NaoH (CA)	0.00998	0.010687	0.009318
conversion%	67	64	69
T(C)	14	14	14
k(L/min*mol)	1.670675	1.268923	1.296334
1/CA	0.1002	0.093571	0.107319
LNK	0.513228	0.238169	0.25954
1/ τ	0.05	0.060606	0.06993

units

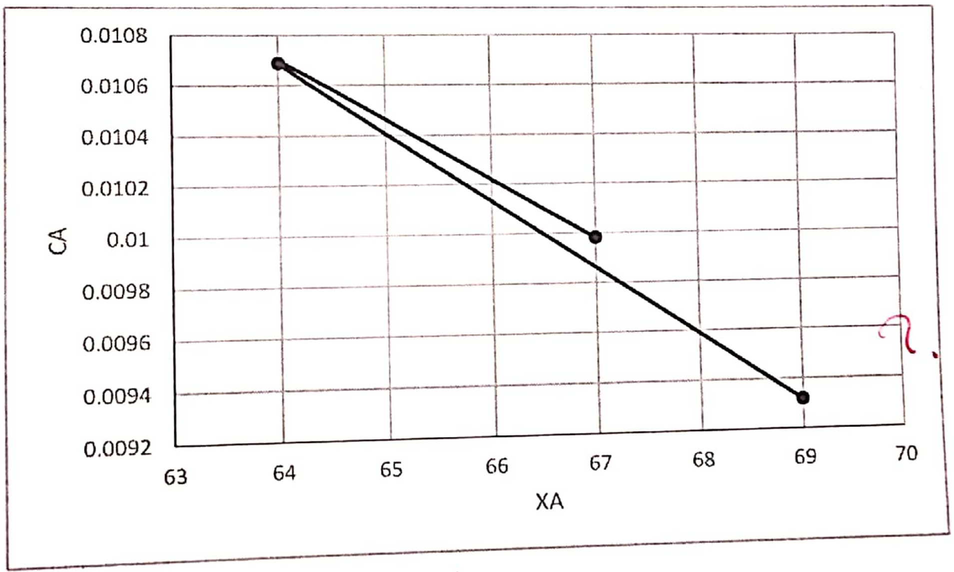


Figure 1: NAOH concentration with Conversion.

- Rate of reaction must be second order reaction.
- A tubular flow reactor is a vessel which the flow is continuous, steady state and organized so that the conversion of the chemicals and other dependant variables are functions of position within the reactor than the time. There is no axial mixing in a tubular reactor.
- In this experiment we study the effect of reactant flowrate on residence time and conversion, as shown in the above table when the flowrate of the reactant increases the residence time will decrease as well as the conversion, thus higher reactants flow rates are not always desirable for practical application.
- The third run the conversion must be less than the conversion in the second run, maybe the reason we've prepared another solution of NaOH and that's call personal error.

Conclusion

- The Rate of reaction must be second order reaction.
- A tubular flow reactor is steady state so the variables are functions of position within the reactor than the time. There is no axial mixing in a tubular reactor.
- There is an inversely relation between flowrate of the reactant and the residence time when flowrate of the reactant increases the residence time the will decrease as well as the conversion.
- higher reactants flow rates are not always desirable.
- personal error Couse the third run the conversion lower than the conversion in the second run

References

- Fogler, S.H., 'Elemets of Chemical Reaction Engineering', 3rd Edition, Prentice Hall, (1999).

Appendix

Sample of calculations

Run number 1 is taken :

$$\tau = \int_{Ca}^{Cao} \frac{dCa}{KCa^2}$$

- Estimation of K value by integral method:

  We Integrate equation (1):

$$\tau = \frac{1}{K}\left(\frac{1}{Ca} - \frac{1}{Cao}\right)$$

$$20 * K = \frac{1}{1000}\left(\frac{1}{0.00998} - \frac{1}{0.06}\right)$$

k = 1.670675 L/mol min

2) Reaction rate as a function of temperature is obtained in Arrhenius equation as below:

$$-rA = K\, {C_A}^n {C_B}^m = K_0 e^{\frac{-E}{RT}} {C_A}^n {C_B}^m$$

?

Tubular's Data Sheet

Item	Run1	Run2	Run3	Run4
Ethyl acetat conc. In feed tank	0.06 $\frac{mol}{dm^3}$	0.06		
Sodium hydroxide conc. In feed tank	0.06 $\frac{mol}{dm^3}$	0.06		
HCl concentration (titrant)	~~0.06~~			
NaOH conc. (titrant)	0.06			
Flow rate of ethylacetate	50 ml/min	60	70	
Flow rate of ethylacetate	50	60	70	
Residence time	20min	16.5min	14.3 min	
Mass of (beaker+15ml of Hcl)				
Mass of (beaker+15ml of Hcl+10ml sample)				
Volume of NaOH (titrant)				
Temperature	14°c	14°c	14°c	

conversion	67%	64%	69%
current ~~Final~~ conc. of NaOH (mol/dm³)	0.00998	0.01068706	0.00931798

8/12/2021

الأزهار

Group# 2

The University of Jordan
School of Engineering
and Technology

85
100

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 5: Hydraulic Analog Methods

Report Type: Short Report

Done By:
Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

Submission Date:22/12/2021

Abstract

The aim of this experiment is to use hydraulic analog approaches to develop kinetic rate equations for different reaction types, which is reversible and irreversible reactions, and orders in batch reactors and study a first order series reaction. Also, it represents first order reaction in a batch reactor in which the volume readings in burette in c$\overset{3}{\text{m}}$3 is to be considered as a concentration of reactant in mole/$\overset{3}{\text{m}}$3.

Result

1) First order irreversible reaction

$$A \overset{\cdot}{\rightarrow} R$$

$$-rA = K\,CA$$

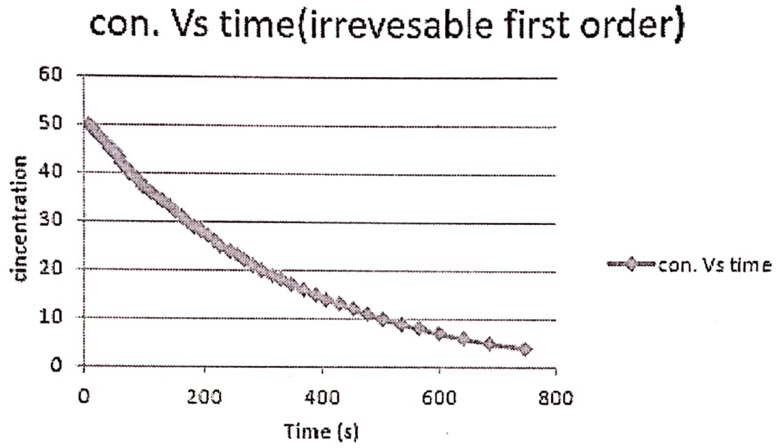


Figure 1concentration profile for irreversible first order reaction

After linearization (integration) equation become:

$$\int_{CA0}^{CA} \frac{-dCA}{CA} = \int_{0}^{t} dt$$

$$\ln \frac{CA0}{CA} = k.t$$

Then Plot ln (Ca0/CA) vs. time, if linear curve is obtained so the reaction is surely first order and value of k is the slop.

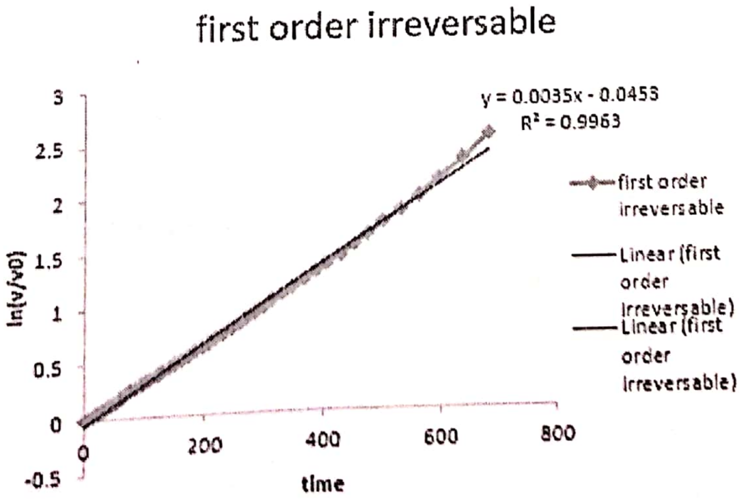


Figure 2linearization for irreversible first order reaction.

So the reaction rate constant K equal 0.0033 1/sec.

$$-rA = 0.0033\ CA$$

2) **First order reversable reaction**

$$A \leftrightarrow R$$

$$-rA = k1\ CA - K2\ R$$

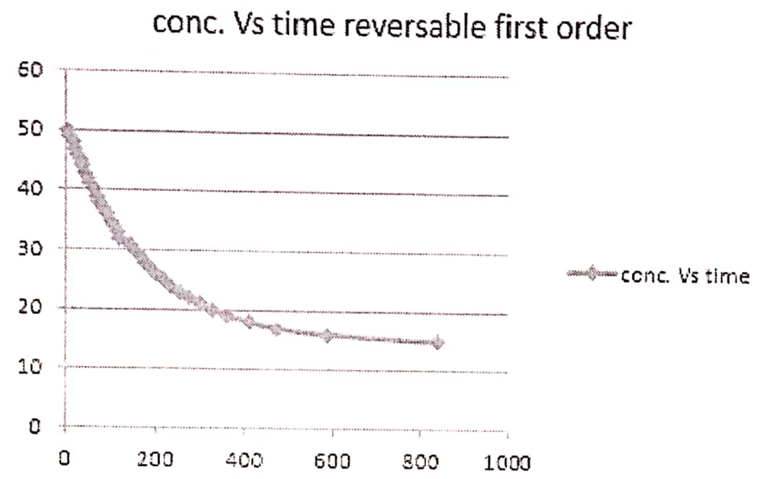


Figure 3concentration profile for first order reverseble reaction.

Now, from the concentration profile, we choose an equilibrium concentration equal 15 ml. From the integration equation

$$Ln\left(\frac{CA - CAe}{CAe}\right) = \ln(k) - (K1 + K2) * t$$

Whereas; K is the equilibrium rate constant and equal k1/k2.

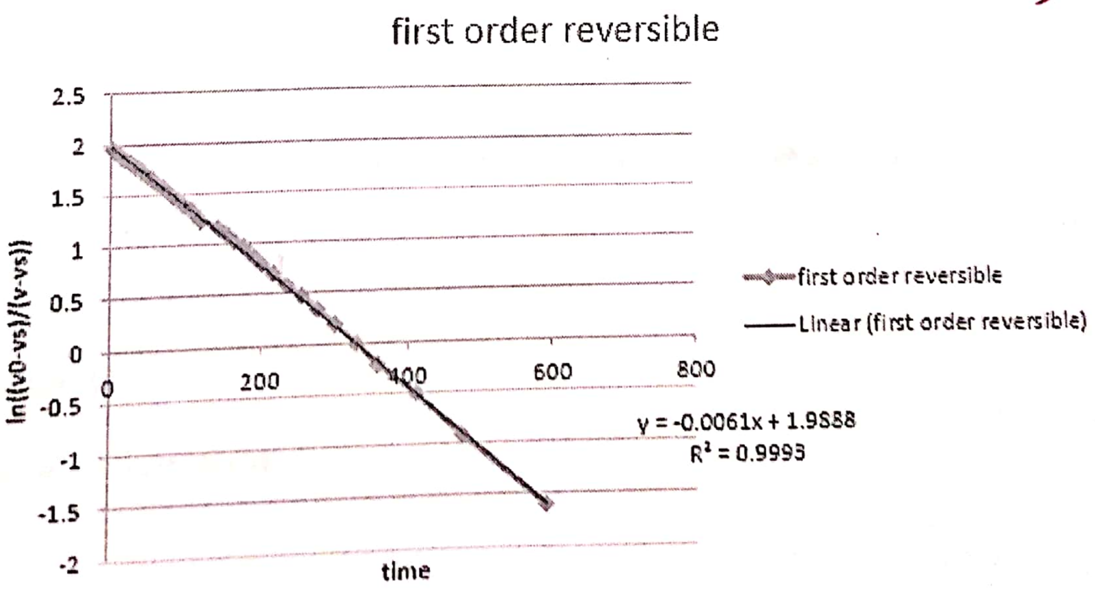


Figure 4linearization for reversible first order reaction

Table 1: the reaction rate constants for irreversible reaction

Slope	-0.0061
Intercept	1.9888
K eq	7.31
K1	0.000734
K2	0.000537

$$-rA = 0.000734\ CA - 0.000537\ R$$

3) Irreversible reaction with order not equal one.

a. Reaction order n > 1

$$A \overset{\cdot}{\rightarrow} R$$

$$-rA = K\ CA^{n}$$

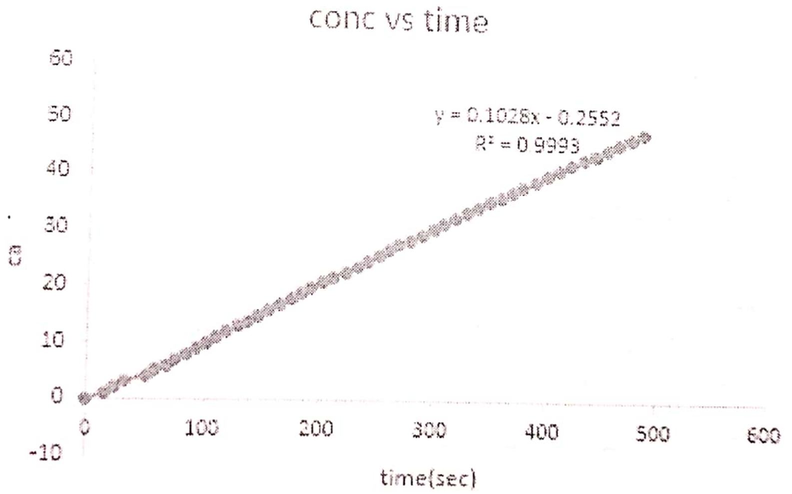


Figure 5 :concentration profile for irreversible reaction with order n>1

After linearization:

$$\ln\frac{-dCA}{dt} = \ln(k) + n\ln(CA)$$

Slope = n

Intercept = ln (K)

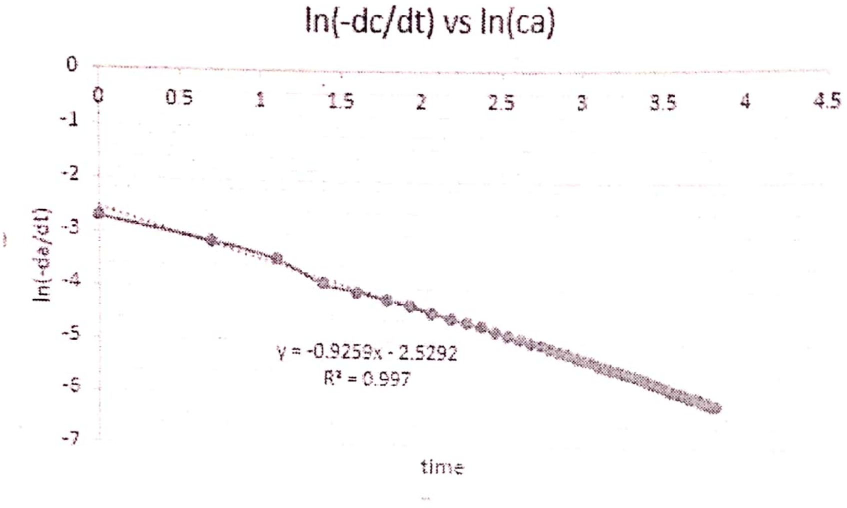


Figure 6linearization for irreversible reaction with order n>1.

Table 2constant rate and order for reaction order>1

Slope	-0.9259
Intercept	-2.592
N	0.9259
k	0.0797

$$-rA = 0.0797\ CA^{0.9259}$$

b. Reaction order n < 1

$$A \overset{\cdot}{\rightarrow} R$$

$$-rA = K\ CA^{n}$$

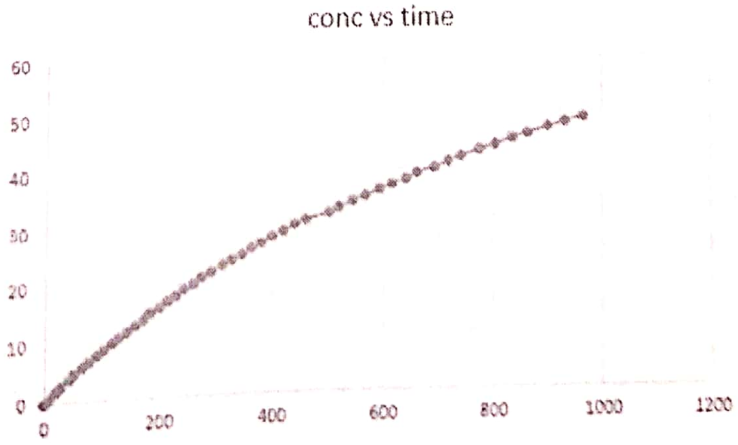


Figure 7 concentration profile for irreversible reaction with order n<1

After linearization:

$$\ln\frac{-dCA}{dt} = \ln(k) + n\ln(CA)$$

Slope = n

Intercept = ln (K)

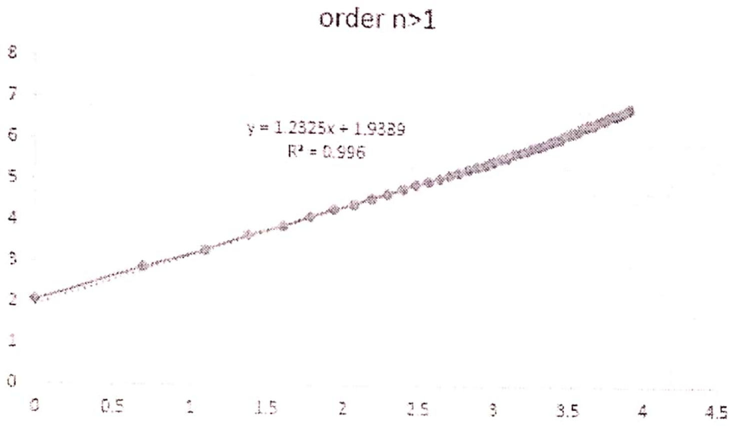


Figure 8:linearization for irreversible reaction with order n<1.

Table 3constant rate and order for reaction order<1

Slope	1.2325
Intercept	1.9389
N	1.2325
k	6.9511

$$-rA = 6.9511\ CA^{1.2325}$$

4)First order series reaction

$$A \rightarrow R \rightarrow S$$

$-ra = K1CA$ AND $-rs = K2CR$

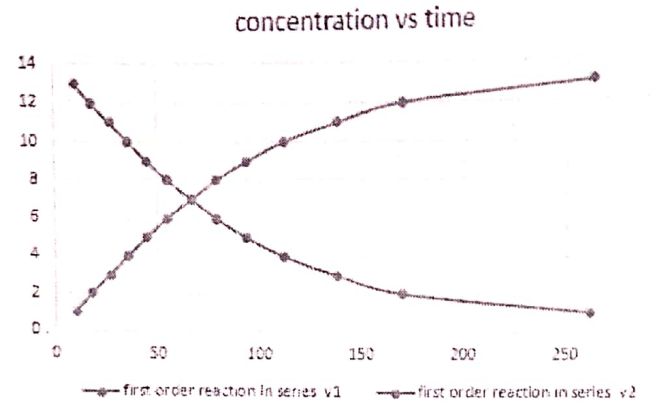


Figure 9: v1 and v2 vs time

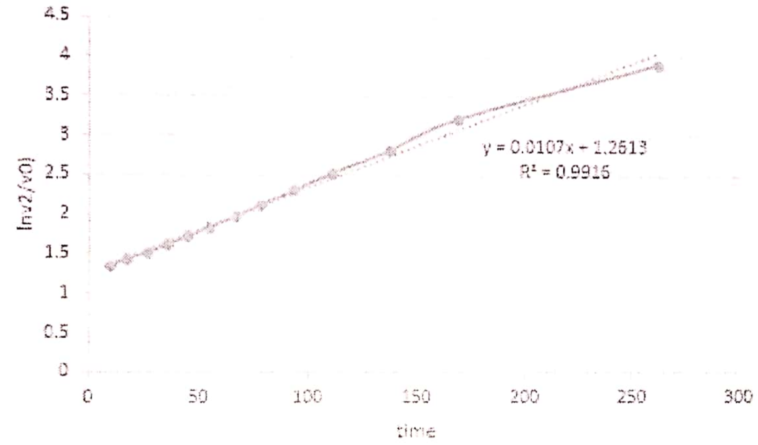
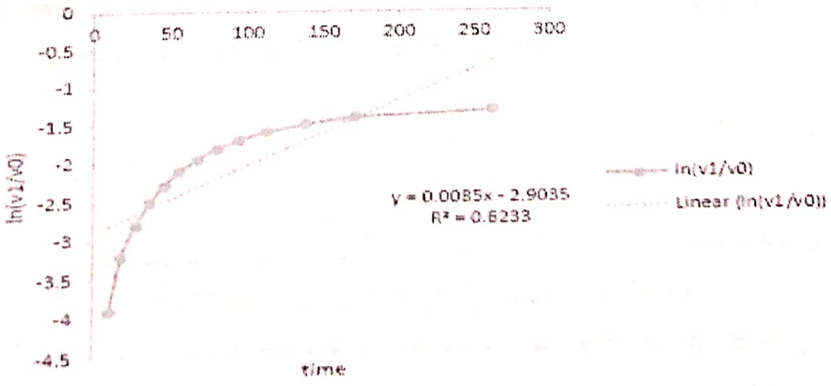


Figure 10: reaction in series ln(v2/v0) vs time

$$-rs = K2CR$$

$$-rs = 0.0107CR$$



$$-ra = K1CA$$

$$-ra = 0.0085CA$$

Discussion

- The rate equation for a chemical reaction shows the change in concentration over time, and the constant parameters can be derived from theoretical considerations or empirical curve fitting.

- The value of the constants of the equation can only be found by experiment. By which the disappearance of reactants and the appearance of products are observed over time.
- The hydraulic analog approach is used to show the generation of kinetic rate equations from laboratory data, Since the derivation of liquid discharge is the same for reactions equations.

- Figure 1, concentration profile for irreversible first order reaction, Where the reactants react to form the products and can't reverse back into reactants. Reactant concentration is decreasing with time until there are no more reactants left.
- Figure 2, linearization for irreversible first order reaction, to find the reaction rate constant (k) and because of the appearance of linear curve then the reaction is first order.

- Figure 3, concentration profile for first order reversible reaction, reactant concentration is decreasing with time until there are no more reactants left. And figure 4 is to find the equilibrium rate constants.
- Nonlinear irreversible reactions are characterized by having reaction order not equal to 1.

- First order series reaction, in series reaction reactant A is converted into product R which in turns is converted into product S.
- Figure 9, shows concentration profile for first order series reaction for the reactant R. Concentration of R reaches a maximum value when A is totally consumed, after that the second reaction begins where R begins to be consumed and its concentration decreases producing product S.

- Figure 10, shows the linearization for first order series reaction, was constructed to find K1 of the series reaction. And to find K2 of the series reaction.

✓

Conclusion

- Hydraulic system analogy is used to represent batch reactors with different reaction types and orders (reversible, irreversible, and series reactions).
- The calculation of reaction rate parameters is done by utilizing the slope and intercept of the data.
- The rate of the reaction depends on the concentration of the reactants.
- The rate constant is a function of temperature.

Appendix

Sample of calculations

First Order Irreversible Reaction

$CA0=50\,\frac{mol}{m3}$

$CA=48\,\frac{mol}{m3}$ t=14s

$$\int_{CA0}^{CA}\frac{-dCA}{CA}=\int_{0}^{t}dt$$

$$\ln\frac{CA0}{CA}=k.t$$

$$\ln\frac{50}{48}=0.0408$$

Plot $\ln\frac{CA0}{CA}$ vs time

Slope = -k = 0.9963

First Order Reversible Reaction

$CAe=14\,\frac{mol}{m3}$ t=840s

$CA=49\,\frac{mol}{m3}$ t=14s

$$-rA=k1\;CA-K2\;R$$

$$Ln\left(\frac{CA-CAe}{CAe}\right)=\ln(k)-(K1+K2)*t$$

Plot $Ln\left(\frac{CA-CAe}{CAe}\right)$ vs t

Intercept=1.9888, k=7.31

Slope= -0.0061 =-(k1+k2)

✓

K1=k2*k1

K1=0.000734

K2=0.000537

reaction order less than 1

volume	time	delta v	CA2-CA1	ca2-ca1/t2-t1	ln(ca2-ca1)/t2-t1	lnca
50	0	0	1			0
49	15	1	1	0.066666667	-2.708050201	0.693147
48	23	2	1	0.043478261	-3.135494216	1.098612
47	32	3	1	0.03125	-3.465735903	1.386294
46	50	4	1	0.02	-3.912023005	1.609438
45	58	5	1	0.017241379	-4.060443011	1.791759
44	67	6	1	0.014925373	-4.204692619	1.94591
43	75	7	1	0.013333333	-4.317488114	2.079442
42	85	8	1	0.011764706	-4.442651256	2.197225
41	94	9	1	0.010638298	-4.543294782	2.302585
40	102	10	1	0.009803922	-4.624972813	2.397895
39	110	11	1	0.009090909	-4.700480366	2.484907
38	120	12	1	0.008333333	-4.787491743	2.564949
37	129	13	1	0.007751938	-4.859812404	2.639057
36	138	14	1	0.007246377	-4.927253685	2.70805
35	147	15	1	0.006802721	-4.990432587	2.772589
34	156	16	1	0.006410256	-5.049856007	2.833213
33	165	17	1	0.006060606	-5.105945474	2.890372
32	175	18	1	0.005714286	-5.164785974	2.944439
31	184	19	1	0.005434783	-5.214935758	2.995732
30	193	20	1	0.005181347	-5.262690189	3.044522
29	203	21	1	0.004926108	-5.313205979	3.091042
28	212	22	1	0.004716981	-5.356586275	3.135494
27	223	23	1	0.004484305	-5.407171771	3.178054
26	234	24	1	0.004273504	-5.455321115	3.218876
25	243	25	1	0.004115226	-5.493061443	3.258097
24	253	26	1	0.003952569	-5.533389489	3.295837
23	262	27	1	0.003816794	-5.568344504	3.332205
22	270	28	1	0.003703704	-5.598421959	3.367296
21	281	29	1	0.003558719	-5.638354669	3.401197
20	291	30	1	0.003436426	-5.673323267	3.433987
19	300	31	1	0.003333333	-5.703782475	3.465736
18	310	32	1	0.003225806	-5.736572297	3.496508
17	320	33	1	0.003125	-5.768320996	3.526361
16	330	34	1	0.003030303	-5.799092654	3.555348
15	340	35	1	0.002941176	-5.828945618	3.583519
14	351	36	1	0.002849003	-5.860786223	3.610918
13	360	37	1	0.002777778	-5.886104031	3.637586
12	371	38	1	0.002695418	-5.916202063	3.663562
11	380	39	1	0.002631579	-5.940171253	3.688879
10	392	40	1	0.00255102	-5.97126184	3.713572
9	402	41	1	0.002487562	-5.996452089	3.73767
8	412	42	1	0.002427184	-6.021023349	3.7612
7	423	43	1	0.002364066	-6.047372179	3.78419
6	434	44	1	0.002304147	-6.073044534	3.806662
5	444	45	1	0.002252252	-6.095824562	

4	455	46	1	0.002197802	-6.120297419	3.828641
3	466	47	1	0.002145923	-6.144185634	3.850148
2	477	48	1	0.002096436	-6.167516491	3.871201
1	487	49	1	0.002053388	-6.188264123	3.89182

reaction order more than 1

volume	time	delta v	lnt(1/2)	ln(v0)
50	0	0		0
49	8	1	2.079442	0
48	18	2	2.890372	0.693147
47	28	3	3.332205	1.098612
46	41	4	3.713572	1.386294
45	51	5	3.931826	1.609438
44	65	6	4.174387	1.791759
43	77	7	4.343805	1.94591
42	89	8	4.488636	2.079442
41	102	9	4.624973	2.197225
40	115	10	4.744932	2.302585
39	128	11	4.85203	2.397895
38	142	12	4.955827	2.484907
37	155	13	5.043425	2.564949
36	171	14	5.141664	2.639057
35	181	15	5.198497	2.70805
34	197	16	5.283204	2.772589
33	212	17	5.356586	2.833213
32	227	18	5.42495	2.890372
31	241	19	5.484797	2.944439
30	257	20	5.549076	2.995732
29	273	21	5.609472	3.044522
28	288	22	5.66296	3.091042
27	308	23	5.7301	3.135494
26	325	24	5.783825	3.178054
25	343	25	5.83773	3.218876
24	360	26	5.886104	3.258097
23	379	27	5.937536	3.295837
22	397	28	5.983936	3.332205
21	418	29	6.035481	3.367296
20	437	30	6.079933	3.401197
19	456	31	6.122493	3.433987
18	499	32	6.212606	3.465736
17	517	33	6.248043	3.496508
16	544	34	6.298949	3.526361
15	566	35	6.338594	3.555348
14	590	36	6.380123	3.583519
13	615	37	6.421622	3.610918
12	640	38	6.461468	3.637586
11	660	39	6.49224	3.663562
10	690	40	6.536692	3.688879
9	717	41	6.575076	3.713572
8	740	42	6.60665	3.73767

7	773	43	6.650279	3.7612
6	803	44	6.688355	3.78419
5	832	45	6.723832	3.806662
4	863	46	6.760415	3.828641
3	899	47	6.801283	3.850148
2	930	48	6.835185	3.871201
1	964	49	6.871091	3.89182

first order reaction in series

time	v1	v2	VR 50-v2	Vs 50-v1/vr	ln(v2/v0)	ln(v1/v0)
10	1	13	37	12	1.347074	-3.91202
18	2	12	38	10	1.427116	-3.21888
27	3	11	39	8	1.514128	-2.81341
36	4	10	40	6	1.609438	-2.52573
45	5	9	41	4	1.714798	-2.30259
55	6	8	42	2	1.832581	-2.12026
67	7	7	43	0	1.966113	-1.96611
79	8	6	44	-2	2.120264	-1.83258
94	9	5	45	-4	2.302585	-1.7148
112	10	4	46	-6	2.525729	-1.60944
138	11	3	47	-8	2.813411	-1.51413
170	12	2	48	-10	3.218876	-1.42712
262	13	1	49	-12	3.912023	-1.34707

Hydraulic Analog's data sheet

rev
rcved

Time (s)	Reaction Volume	Reaction Volume	Reaction Volume	Reaction Volume	Reaction Volume
3 4					
3 10					
4 15					
4 20					
26					
31					
37					
42					
49					
55					
min 1					
1:10					
1:15					
1:22					
1:30					
1:38					
1:46					
1:55					
2					
2:13					
2:23					
2:34					
2:45					
1:56					
3:10					
3:22					
3:38					
3:55					
4:16					
4:37					
5 ~~4:50~~					
5:30					
6					
6:51					
7:54					
9:50					
~~15:19~~ 14					

15/12/2021

flask

Time

~~0 50~~

~~22~~
(5)
0
08
18
28
41
51
1:05
1:17
1:29
1:42
1:55
2:08
2:22
2:35
2:51
3:01
3:17
3:32
3:47
4:01
4:17
4:33
4:48
~~4:~~5:08
5:25
5:43
6:00
6:19
6:37
6:58
7:17
7:36
8:19
8:42
9:04
9:26
9:50
10:15
10:40
11:06
11:30
11:57
12:20
12:53
13:23
13:52
14:23
14:59
15:30
16:04

ries

time	hight
0	0
10	
18	
27	
36	
45	
sec 55	
min 1.07	
1.19	
1.34	
1.52	
2.18	
2.50	
[illegible] 4.22	38.5

Funnel

100

time	Rn volum
0	0
.15	1cm
23	
32	
41	
50	
sec 58	
[illegible] 1.07	
[illegible] 1.15	
min 1.25	
1.34	
1.42	
1.50	
2.00	
2.09	
2.18	
2.27	
2.36	
2.45	
2.55	
3.04	
3.13	

time
3.23
3.32
3.43
3.54
4.03
4.13
4.22
4.30
4.41
4.51
5.00
5.10
5.20
5.30
5.40
5.51
6.00
6.11
6.20
6.32
6.42
6.52
7.03
7.14

time
7.24
7.35
7.46
7.57
8.07

[redacted]

2 15

الأردني

Group #2

The University of Jordan
School of Engineering and Technology

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 6: level control

Report Type: Short Report

Done By:
Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

85/100

Submission Date:8/12/2021

Abstract

The response of a system (coupled tanks apparatus) to different control system was investigated in the experiment. The control system used include proportional control(P)and proportional integral control (PI). The aim of this experiment was controlling the water level in process tank by using different control system.

First part of experiment we made calibration of the pump by find the relation between flowrate and voltage, second part study the performance of the controller at different value of its parameter.

Result

Tabulated result

Part a : Depth Sensor Calibration	Gd=0.0004 volt/cm
Part b : Pump Calibration	Gp=2.188 ml/volt.s
Part c: Dynamic Characteristics	$G2 = \frac{0.34}{(251.04S + 1)(31.65S + 1)}$ $G1 = \frac{0.5995 + 26.41S}{(251.04S + 1)(31.65S + 1)}$
Part D: Steady State Operating Levels	$H_{s1,theo.} = 12.6\ cm$
Design of the proportional and proportional plus integral controllers	$\zeta = \frac{\tau1 + \tau2}{2\sqrt{\tau1\tau2(K_PG + 1)}} = 0.9$ ⇒ <u>underdamped</u>

Graphical result

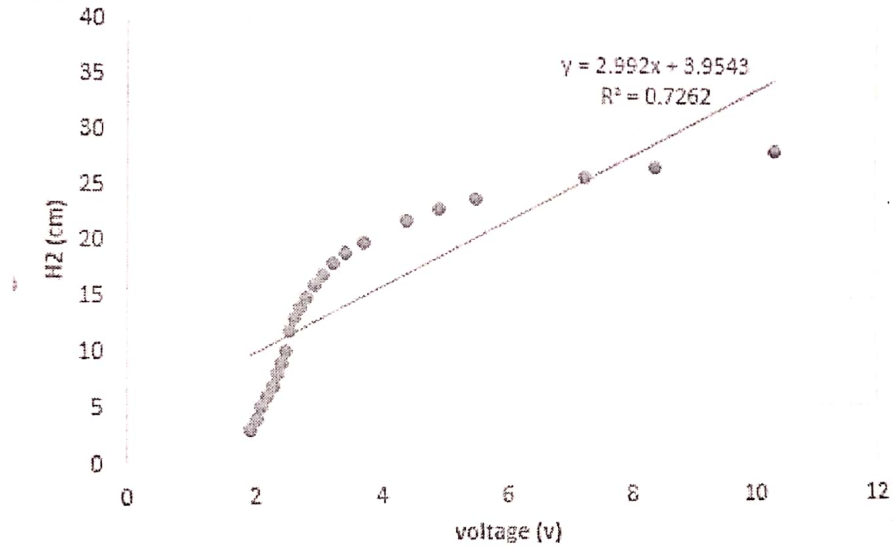
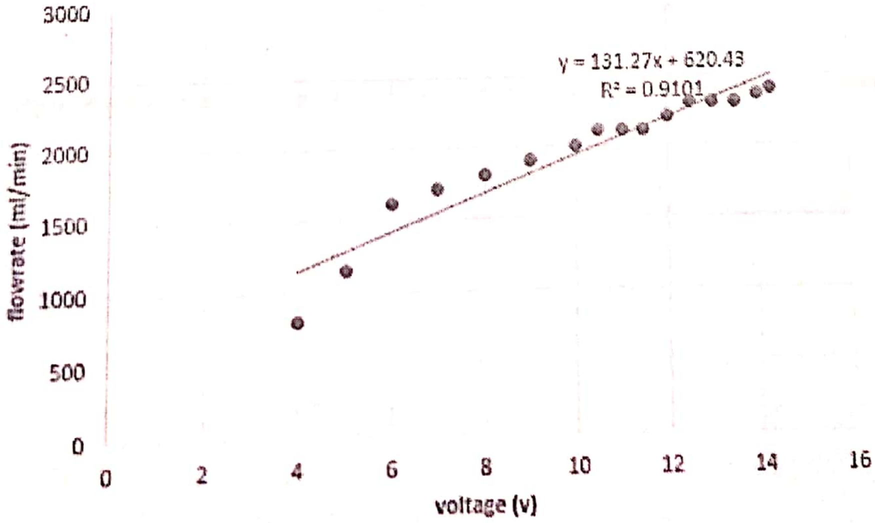


Figure 1 Relation between H2 (cm) vs. voltage (V)

✓



✓

Figure 2 Relation between Flowrate (ml/min) vs. voltage (V)

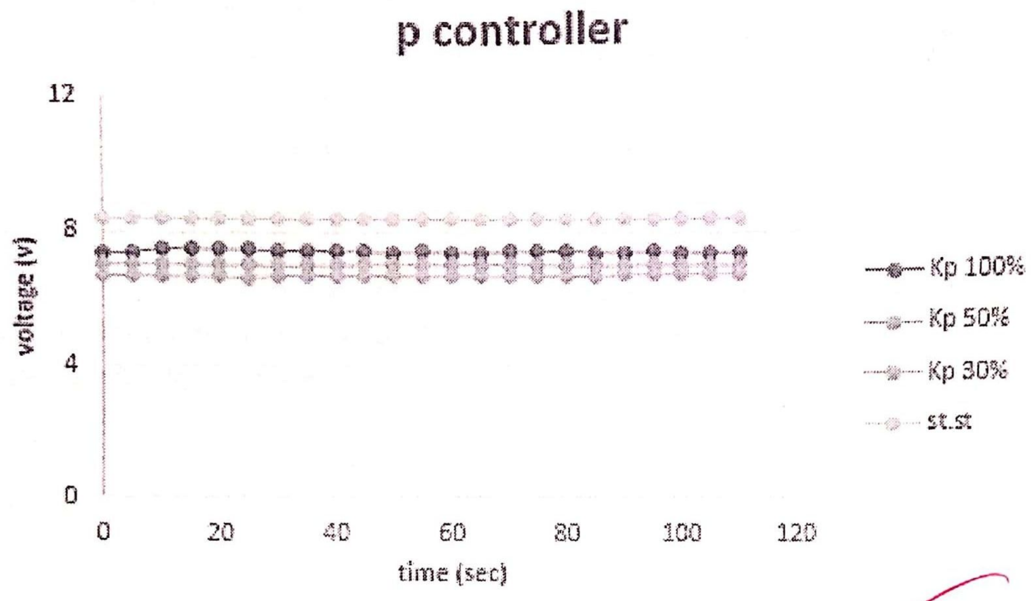


Figure 3 The effect of different values of Kp on the tank transmitted voltages (V) related to the tank level vs. time (s)

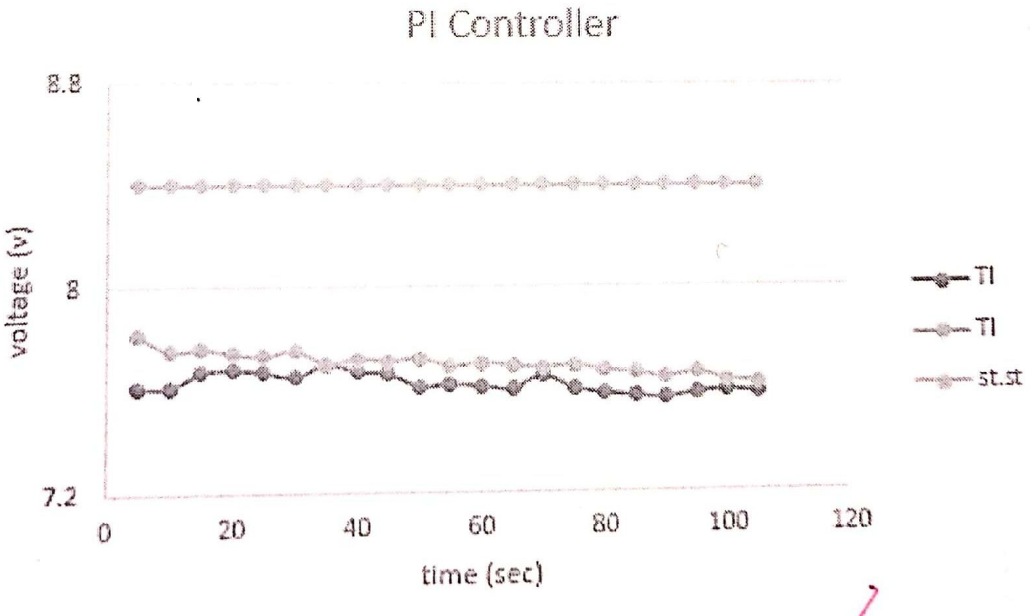


Figure 4 The effect of different values of τi on the tank transmitted voltages (V) related to the tank level vs. time (s)

Discussion

- In the Figure 1 we see a plot of the voltage against the level, we can see that level is probational to voltage as the level is decreased, the corresponding voltage is decreased as well. Measuring Device characteristic = Gd (V/cm) = 0.0004
- Steady state characteristics of final control element (Pump) Figure 2 shows a plot of the voltage against the flow, we can see that as the voltage applied is increased, the corresponding flowrate increases as well. Pump characteristic: Gp (ml/(s.V)) = slope = 2.188.
- The physical system can be represented by second-order transfer function, which arises when two first-order processes are connected in series. Transfer functions obtained.

  Transfer Function for first system:

$$G1 = \frac{0.5995 + 26.41S}{(251.04S + 1)(31.65S + 1)}$$

  Transfer Function for second system:

$$G2 = \frac{0.34}{(251.04S + 1)(31.65S + 1)}$$

  So, We note that $\tau 1$ is greater than $\tau 2$

- The steady state level in tank 1 is (H 1s,th = 12.5cm), while the experimental level is (H,1s,exp =17 cm) There is a deviation that results in 26% error.
- P-controller is a type of linear feedback control system in which a correction is applied to the controlled variable which is proportional to the difference between the desired value (set point) and the measured value (process variable, PV)

  From Figure 3 we note that experimental and theoretical errors (of voltage) have very close values for Kp=100, Kp=50 and Kp=30.
- A P.I Controller is a feedback control loop that calculates an error signal by taking the difference between the output of a system

✓

Conclusion

- In Control systems there are the three requirements, stability, accuracy, and speed of response.
- PID controller is an instrument used in industrial control applications to regulate temperature, flow, pressure, speed and other process variables. It has three parameters: Proportional (P), Integral (I), and Derivative (D).
- P controller is used in chemical industry plants and it is the simplest and fastest, while PI and PID are much complicated controllers.
- This experiment is used to prevent fluids level in the tank from being overflow or under specific level determined as process conditions required.

References

1. GEORGE STEPHANOPOULOS, "Chemical Process Control- An introduction into theory and practice- ", Department of Chemical Engineering-Massachusetts institute of Technology.

2. Seborg, Edgar, Mellichamp, Doyle, "Process Dynamics and Control", third edition.

3. Chemical Engineering Laboratory (4) Manual

Appendix

Sample of calculations

Measurements of system characteristics:

Part (A): Depth Sensor Calibration:

The relation between voltage (outlet stream from the pump) and the heights (inlet stream to the pump) is linear and the following equations represent this case:

Voltage= 1 m x height $\Rightarrow \frac{Y(S)}{X(S)} = \frac{1}{m}$

Where; (m) is the slope of the straight line in (Figure (1)):

$$Gd = \frac{Y(s)}{X(s)} = \frac{1}{2.992} = 0.3334\ (volt/cm)$$

✓

Part (B): Pump Calibration:

The relation between voltage (inlet stream to the pump) and the flowrate (outlet stream from the pump) is linear and the following equations represent this case:

$$Flowrate = m\ x\ voltage \Rightarrow \frac{Y(s)}{X(s)} = m$$

Where; (m) is the slope of the straight line in (Figure (2)):

$$GP = \frac{Y(s)}{X(s)} = \frac{126.38}{60} = 2.188\ (ml/volt.s)$$

✓

Part (C): Dynamic Characteristics:

When the flowrate of the water equals 2800 ml/min, the steady state value for both tanks is: The first tank (Hs1) = 17 cm and the second tank (Hs2) = 11 cm

$$c\ d1\ a1\sqrt{2g} = \frac{Qi}{\sqrt{H1 - H2}} = \frac{2800/60}{\sqrt{17 - 11}} = 19.05$$

$$c\ d2\ a2\sqrt{2g} = \frac{Qi}{\sqrt{H2 - H3}} = \frac{\frac{2800}{60}}{\sqrt{11 - 3}} = 16.499$$

$$K1 = \frac{c\ d1\ a1\sqrt{2g}}{2 * \sqrt{H1 - H2}} = \frac{19.05}{2 * \sqrt{17 - 11}} = 3.89\ (cm2/s)$$

$$K2 = \frac{c\ d2\ a2\sqrt{2g}}{2 * \sqrt{H2 - H3}} = \frac{16.499}{2 * \sqrt{11 - 3}} = 2.92\ (cm2/s)$$

✓

$$\tau1\tau2 = \frac{A^2}{K1K2} = \frac{300}{3.89 * 2.92} = 7923.37sec2$$

$$\tau1 = \frac{7923.37}{\tau2}$$

$$\frac{\quad}{K1K2} = 282.6$$

$\tau 1 = 251.04\ sec$

$\tau 2 = 31.65$sec

The transfer function of the second tank is given by the equation:

$$G2 = \frac{\frac{1}{K2}}{(S\tau 1 + 1)(S\tau 2 + 1)} = \frac{0.34}{(251.04S + 1)(31.65S + 1)}$$

The transfer function of the first tank is given by the equation:

$$G1 = \frac{\frac{K1 + K2}{K1 * K2} + \frac{A}{K1K2}S}{(S\tau 1 + 1)(S\tau 2 + 1)} = \frac{0.5995 + 26.41S}{(251.04S + 1)(31.65S + 1)}$$

Part (D): Steady State Operating Levels:

The experimental steady state level when the water flow rate equals 2800ml/min, Hs1 = 17cm and Hs2 = 11cm

$$a1 = \frac{\pi D^2}{4} = \frac{\pi (0.95)^2}{4} = 0.709\ cm$$

$$a2 = \frac{\pi D^2}{4} = \frac{\pi (0.635)^2}{4} = 0.317\ cm$$

The theoretical steady state level for tank 1 is related to

$$H_{s1,theo.} = H_{s2}\left[1 + \left(\frac{a2}{a1}\right)^2\right] - H_3\left(\frac{a2}{a1}\right)^2 = 11 * \left[1 + \left(\frac{0.317}{0.709}\right)^2\right] - 3 * \left(\frac{0.317}{0.709}\right)^2 = 12.6cm$$

The experimental height is found to be 17cm

To calculate the error:

$$Error = \frac{H1, exp. - H1, theo.}{Hs1, exp.} = \frac{17 - 12.6}{17} = 0.26$$

- Design of the proportional and integral controllers:

Part (a): Steady State errors using proportional controller:

Experimental steady state error:

$$ess, exp = required\ level - H2s, exp = Yr - H2s, exp = 27 - 11 = 16\ cm$$

The theoretical height of the second tank can be calculated with the following equations:

$$H_{1s,th} = H_{2s,th}\left(1 + \left(\frac{a2}{a1}\right)^2\right) - H3\left(\frac{a2}{a1}\right)^2 = H_{1s,th} = 1.199H_{2s,th} - 0.599$$

$$C\,d1\,a1\sqrt{2g} = \frac{Q_i}{\sqrt{H_{1sth} - H_{2s,th}}} = 0.6 * 0.709 * \sqrt{2 * 980.66} * \sqrt{1.199H_{2s,th} - 0.599} = \frac{2800}{60}$$

$$H_{2s,th} = \frac{\frac{(\frac{2800}{60})^2}{18.883^2} - 0.599}{0.199} = 27.68cm$$

Theoretical steady state error:

ess,theo. = 27 – 27.68 = -0.68 cm

- The transfer function of the process is:

$$G = \frac{G_d G_p}{K_2} = \frac{0.3334 * 2.188}{2.92} = 0.25$$

The damping factor:

$$\zeta = \frac{\tau1 + \tau2}{2\sqrt{\tau1\tau2(K_pG + 1)}} = \frac{251.04 + 31.65}{2\sqrt{251.04 * 31.65(8.4 * 0.25)}} = 0.9$$

$\Rightarrow$ underdamped

The natural frequency

$$\omega n = \sqrt{\frac{Kp\ G + 1}{\tau1\ \tau2}} = \sqrt{\frac{4.8 * 0.25 + 1}{251.04 * 31.65}} = 0.02$$

Resonant frequency:

$$\omega r = \frac{\omega n}{\sqrt{1 - 2 * \zeta^2}} = 0.14$$

Fractional overshoot:

$$F0 = exp\frac{-\zeta\pi}{\sqrt{1 - \zeta^2}} = 0.05$$

ump calibration:

Cm Flowrate ~~(ml/min)~~	V ~~Voltage (V)~~
28.5	10.34
27	8.40
26	7.27
25	6.30
24	5.50
23	4.90
22	4.40
20	4.01
19	3.70
18	3.42
17	3.22
16	3.05
15	2.91
14	2.80
13	2.70
12	2.60
11	2.54
10	2.47
9	2.40
8	2.33
7	2.27
6	2.19
5	2.07
4	2.00
3	1.93

11|12|2022

Dynamic chracteristics:

Flowrate (ml/min)	Hs1 (cm)	Hs2 (cm)

Level Control Data Sheet

Measuring Device calibration:

mL/min ~~H_2 (cm)~~	~~H_2 (V)~~
2400	14.27
2350	14.01
2300	13.50
2300	13.00
2300 ~~2250~~	12.5
2300	12.01
2100	11.5
2100	11.01
2100	10.5
2000	10
	~~9.5~~
1900	9
1800	8
1700	7
1600	6
1150	5
800	4
	3
	2
	1

4/12/2022

Seen

Proportional Controller:

27 cm = 8.4 V

Set point=			
Time	**K_p =** 100%	**K_p =** 50%	**K_p =** 30%
5	~~6.8~~ 7.4	7.05	6.71
10	7.53	7.05	6.70
	7.52	7.04	6.69
	7.51	7.03	6.68
	7.49	7.04	6.66
	7.49	7.02	6.70
	7.46	7.03	6.72
	7.45	7.03	6.73
	7.43	7.04	6.71
	7.42	7.05	6.72
	7.43	7.05	6.69
	7.42	7.05	6.70
	7.41	7.04	6.68
	7.43	7.05	6.70
	7.44	7.05	6.70
	7.46	7.03	6.71
	7.42	7.03	6.72
	7.42	7.04	6.66
	7.43	7.04	6.73
	7.41	7.04	6.71
	7.40	7.04	8.72
	7.41	7.03	6.70
Steady state values:	7.40		
Q (ml/min)	2800 cm³/min	1650	1400
Hs1 (cm)			
Hs2 (cm)			

1/12/2021

7.41
7.40
7.40
7.41
7.42
7.41
7.40
7.42
7.45
7.40
7.45
7.41
7.43
7.40
7.42
7.42
7.38
7.40
7.40
7.38
7.39
7.38
7.37
7.46
7.42
7.47
7.48
7.40
7.40
7.40

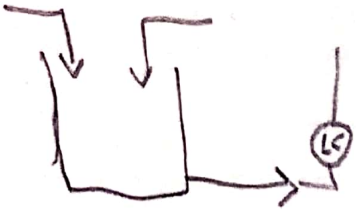
7.03
7.04
7.02
7.03
7.03
7.02
7.03
7.03
7.05
7.06
7.05
7.03
7.04
7.04
7.06
7.05
7.06
7.05
7.05
7.04
7.06
7.04
7.05
7.07
7.04
7.05
7.05
7.05
7.04
7.03
7.05
7.03
7.05
7.06
7.05
7.03
7.03
7.05
7.05
7.02
7.01
7.01

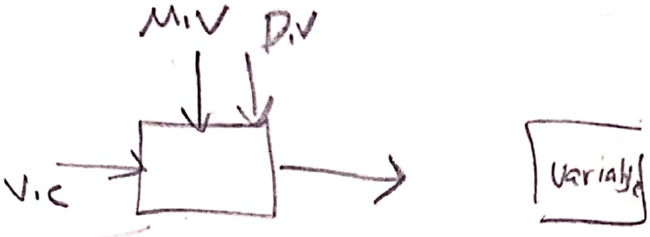
oportional and Integral Controller:

	Set point= 8.4		
	K_p = 8.4		
Time	τ_i =	τ_i =	τ_i =
	7.6[illegible]	7.81	
	7.61	7.75	
	7.67	7.76	
	7.68	7.74	
	7.67	7.73	
	7.66	7.75	
	7.70	7.70	
	7.67	7.72	
	7.66	7.71	
	7.61	7.72	
	7.62	7.69	
	7.61	7.70	
	7.60	7.69	
	7.75	7.68	
	7.60	7.69	
	7.58	7.67	
	7.57	7.66	
	7.56	7.64	
	7.58	7.66	
	7.59	7.63	
	7.58	7.62	
Steady state values:			
Q (ml/min)	2400	2200	
Hs1 (cm)			
Hs2 (cm)			

1/12/2021

Scanned with CamScanner





7.55
7.57
7.55
7.54
7.56
7.57
7.58
7.57
7.56
7.56
7.56
7.53
7.54
7.49
7.50
7.52

7.61
7.61
7.62
7.62
7.63
7.60
7.60
7.59
7.57
7.60
7.63
7.58
7.63
7.60
7.58
7.60
7.96
7.63
7.67
7.62
7.60
7.59
7.61
7.63
7.60
7.58
7.62
7.56

Group #2

الأربعاء

The University of Jordan
School of Engineering
and Technology

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 8: Empirical Dynamic Models

Report Type: Short Report

$\frac{65}{100}$

Done By:

Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

Submission Date:17/11/2021

bstract

There are two ways to generate a dynamic model of a process, either by theoretical or empirical methods. The aim of this experiment to generate an empirical model it is are based on input/output data. The empirical model is not of high accuracy.

In this experiment we make different change on set point (impulse change, step up and step down), the response of the process of each change is recorded with time and plotted as process curve.

There are different methods to calculate, to and K_p, they are shown in detail in this report.

main
Results. ?

Result

Part 1: Step up change

#Method 1

	Method1
t_p	19.7
t0	0.6
k_p	1.090909

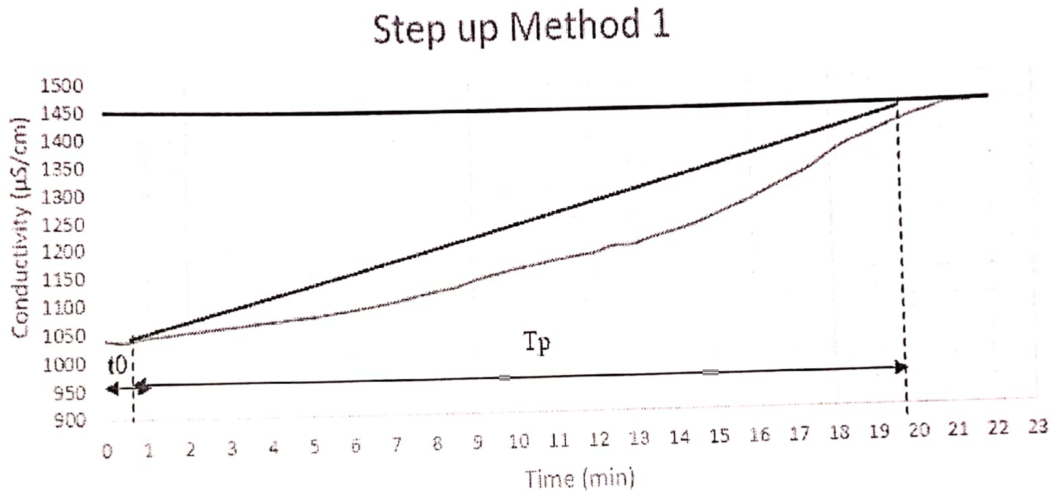


Fig ———

#Method 2

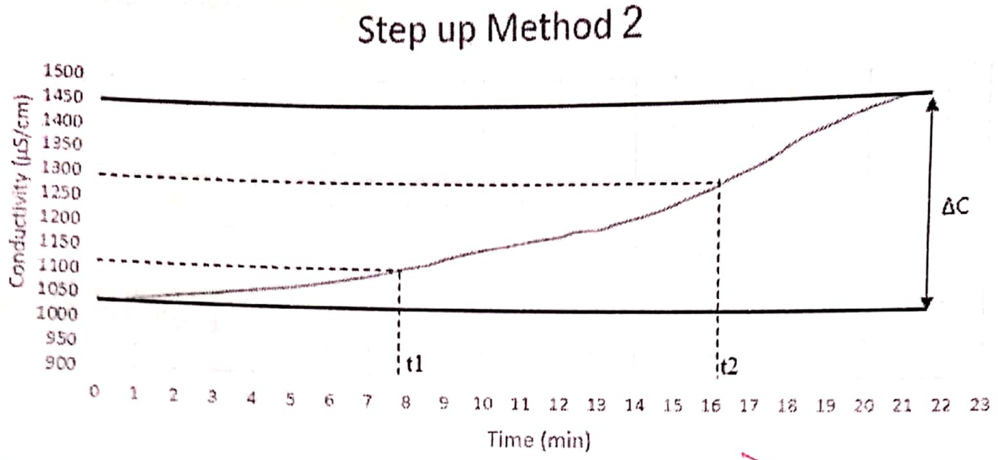
	Method2
t_p	12.3
t0	3.8
k_p	1.090909

$$conductivity\ at\ \tau_1 = 0.283 * \Delta C = 1296.85 \rightarrow \tau_1 = 7.9\ min$$

$$conductivity\ at\ \tau_2 = 0.632 * \Delta C = 1154.45 \rightarrow \tau_2 = 16.1\ min$$

✓

Page (no.)

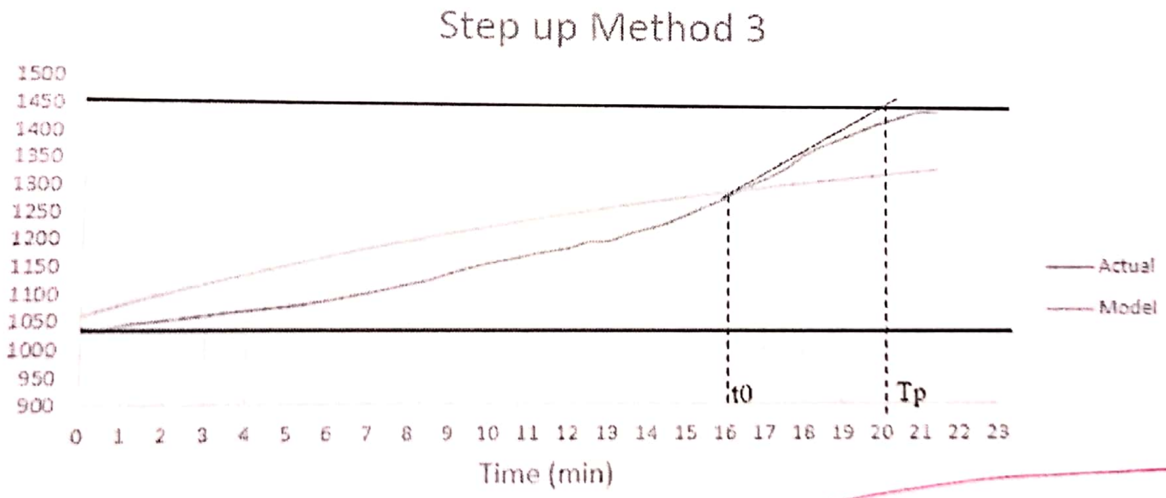


Step up Method 2

Fig (no)

#Method 3

	Method2
t_p	20
t0	16
k_p	1.090909



Step up Method 3

Fig

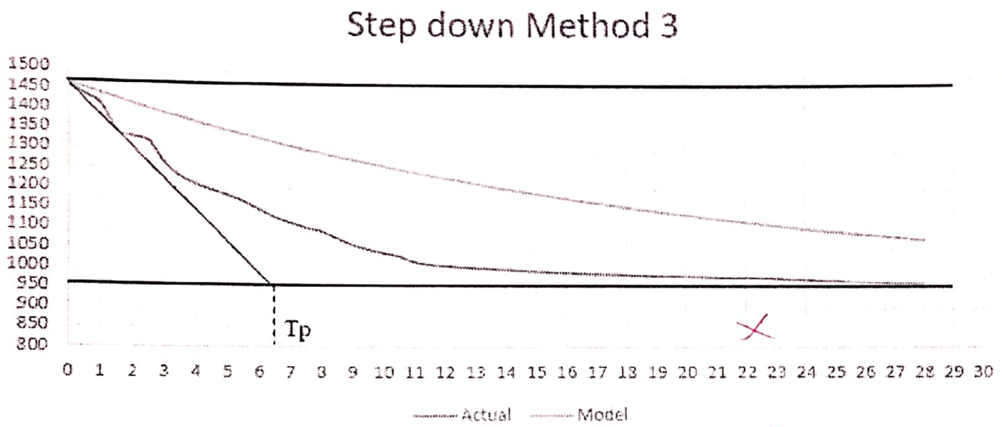
table

	method1	method 2	method 3
tp	19.7	12.3	20
t0	0.6	3.8	16
kp	1.090909	1.090909	1.090909

Part 2: Step down change

#Method 1

	Method1
t_p	6.2
t0	0
k_p	1.020747



y

x

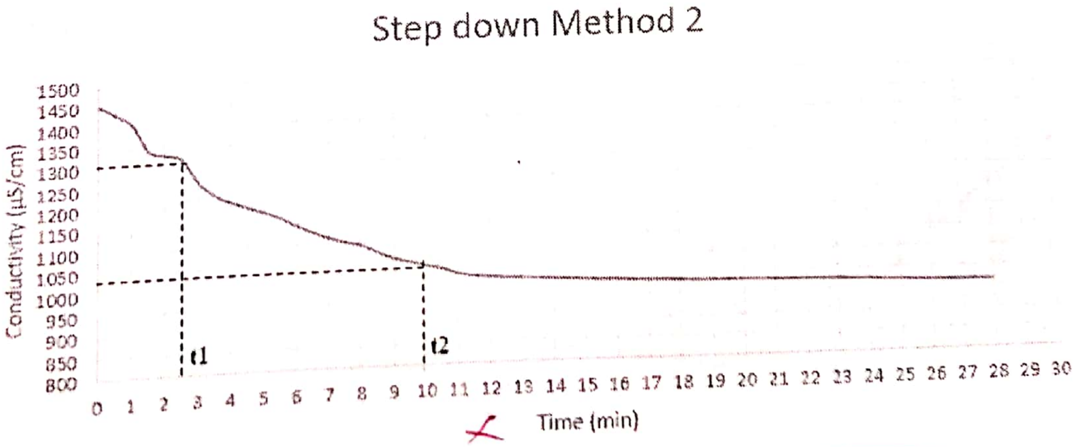
Fig

#Method 2

	Method2
t_p	11.25
t0	1.25
k_p	1.020747

$conductivity\ at\ \tau_1 = 0.283 * \Delta C = 1146.05 \rightarrow \tau_1 = 2.5\ min$

$conductivity\ at\ \tau_2 = 0.632 * \Delta C = 1317.76 \rightarrow \tau_2 = 10\ min$



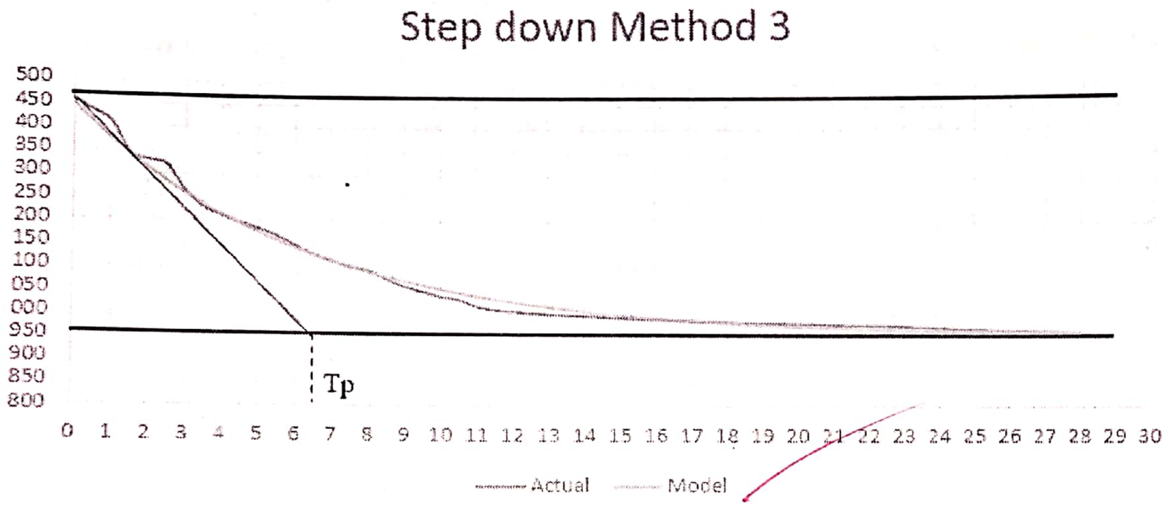
y

x

Fig(

#Method 3

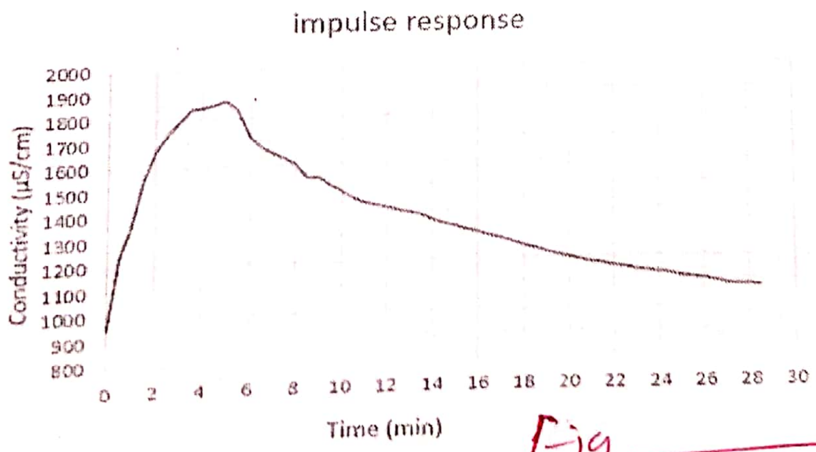
	Method2
t_p	6.5
t0	0
k_p	1.020747



table

	method1	method 2	method 3
tp	6.2	11.25	6.5
t0	0	-1.25	0
kp	1.020747	1.020747	1.020747

Part 3: Impulse change



Fig

Discussion

- Empirical dynamic models are not of high accuracy since they are considered as linear approximations of non-linear processes. Besides, the data may be influenced by unmeasured disturbances, and noises, which may result in errors in sensor measurements.
- The magnitude of the change is large enough for the consequent change in the transmitter signal to be detected, but it isn't so large that will cause disturbances.
- The magnitude of the change is large enough for the consequent change in the transmitter signal to be detected, but it isn't so large that will cause disturbances.

  i. $K_p = \frac{\Delta C}{\Delta m}$ ii. t_0 and τ_p are determine using three different graphical methods.
- The parameters of step up change, figures 1, 2 and 3, are difference in the values of t_0 and τ_p while the value of K_p remain constant.
- The parameters of step down change, figures 4, 5 and 6, are difference in the values of t_0 and τ_p while the value of K_p remain constant.
- The parameters of the response to the pulse change, figure 7, couldn't be estimated since the three methods aren't applicable in this case.

Conclusion and Recommendation

- Empirical models are based on input/output data and only describes the relationship between the measured input output data for the process.
- The model described by method 1 is subjected to large errors, due to calculation of maximum slope.
- The dynamic empirical models skip the physical characteristics of the system, when describing the nature of the system, and the way it responds to change. Large errors are expected, especially if the nature of the physical properties is described by non-linear behavior.
- Step change results in a very rapid change so that t0 (Dead time) is approximately around zero. While Pulse change is a brief sudden change due to sudden change in the input variable within the system.

Appendix

For step up change:

- $\Delta C = final\ value\ of\ conductivity - initial\ value\ of\ conductivity$
  $= 1447 - 1039 = 408$
- $\Delta m = final\ value\ of\ conducivity - initial\ pure\ water\ conductivity$
  $= 1447 - 1073 = 374$
- $k = \frac{\Delta C}{\Delta m} = \frac{408}{374} = 1.09$

➢ Method (1):

$from\ plot\ shown\ in\ figure(1), \tau_p = 19.7,\ \tau_0 = 0.6$

$k = 1.09$

➢ Method (2):

$conductivity\ at\ \tau_1 = 0.283 * \Delta C = 1296.85 \rightarrow \tau_1 = 7.9\ min\ conductivity$
$at\ \tau_2 = 0.632 * \Delta C = 1154.45 \rightarrow \tau_2 = 16.1\ min$

$\rightarrow \tau_1 = 7.9$ min $(from\ diagram)$.

$\rightarrow \tau_2 = 16.1$ min $(from\ diagram)$.

- ✓ $k = 1.09$
- ✓ $\tau_p = \frac{3}{2} * (\tau_2 - \tau_1) = \frac{3}{2}(16.1 - 7.9) = 12.3\ min$
- ✓ $\tau_0 = \tau_2 - \tau_p = 16.1 - 4.335 = 3.8\ min$

Seen

➢ Method (3):

$from\ plot\ shown\ in\ figure(3), \tau_p = 20\ min,\ \tau_0 = 16\ min.\ k = 1.9$

To find the actual data for example at time= 1 min,

$$c(t) = k * \Delta m * (1 - \exp\left(-\frac{t - \tau_0}{\tau_p}\right))$$

$$= 1.09 * 374 * \left(1 - \exp(-\frac{1 - 0.6}{19.7}\right) = 8.2$$

$$C(t) = c(t) + c_0(t) = 8.2 + 1073 = 1091.22 \frac{\mu S}{cm}$$

The same calculations are done for step down change .

Empirical Dynamic Models Data Sheet:

Impulse response:

Initial process tank conductivity:

Injected solution conductivity:

Time (s)	Conductivity	Time	Conductivity
0	952	870	1348
30	1236	900	1334
60	1367	930	1319
90	1550	960	1305
120	1669	990	1291
150	1734	1020	1279
180	1791	1050	1266
210	1836	1080	1250
240	1844	1110	1237
270	1851	1140	1223
300	1870	1170	1211
330	1830	1200	1198
360	1716	1230	1188
390	1676	1260	1179
420	1647	1290	1171
450	1624	1320	1162
480	1601	1350	1154
510	1576	1380	1148
540	1544	1410	1140
570	1514	1440	1134
600	1484	1470	1127
630	1460	1500	1121
660	1439	1530	1115
690	1427	1560	1108
720	1415	1590	1097
750	1403	1620	1088
780	1394	1650	1083
810	1381	1680	1078
840	1364	1710	1073

Seen

10/11/2021

ep up response:

ial process tank conductivity:

nitial water tank conductivity:

Initial solution tank coductivity:

Time	Conductivity	Time	Conductivity
0	1039	870	1235
30	1036	900	1250
60	1044	930	1266
90	1048	960	1283
120	1053	990	1301
150	1057	1020	1318
180	1061	1050	1336
210	1066	1080	1362
240	1070	1110	1382
270	1074	1140	1396
300	1078	1170	1412
330	1083	1200	1426
360	1089	1230	1437
390	1096	1260	1448
420	1103	1290	1457
450	1111	1320	
480	1120	1350	
510	1128	1380	
540	1146	1410	
570	1150	1440	
600	1159	1470	
630	1166	1500	
660	1174	1530	
690	1181	1560	
720	1187	1590	
750	1199	1620	
780	1201	1650	
810	1214	1680	
840	1224	1710	

10/11/2021

Seen

Step down response:

Initial process tank conductivity:

Initial water tank conductivity:

Time	Conductivity	Time	Conductivity
0	1457		
30	1437		998
	1410		996
	1344		994
	1330		992
	1319		991
	1263		989
	1229		988
	1211		987
	1196		986
	1184		984
	1168		983
	1148		983
	1129		982
	1115		981
	1103		980
	1094		979
	1076		979
	1060		978
	1049		977
	1039		975
	1032		974
	1025		972
	1017		971
	1010		~~97~~ 969
	1007		968
	1004		967
	1002		968
	1000		966
			965

10/11/2021

الدرجار

Group#2

The University of Jordan
School of Engineering
and Technology

Chemical Engineering Department
Chemical Engineering - Laboratory 4

Experiment 9: Process control

Report Type: Short Report

Done By:
Raneem Yameen 0172634
Sawsan Al Haj Mohammad 0172487
Roaa Nasri 0171506
Marwa AL-Bkairat 0172995
Saja Abu Al-Haija 0172660

80/100

Submission Date:29/12/2021

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 P, PI and the PID controller of the level control. The experiment was carried out using the process control system and the control done also the result show up via computer software. The system is a rig consisting 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. A PID controller continuously minimize the calculated error value.

Result

Part1: Characteristics of the pump

Table 1:characteristics of the pump

voltage	time (s)	flow (L/hr)	flow (Cm^3/sec)	volume(cm^3)
3	97	45	12.5	5
4	56	72	20	5
5	49	84	23.33	5
6	44	102	28.33	5
7	33	124	34.44	5
8	29	140	38.89	5
9	26	153	42.5	5
10	24	166	46.11	5

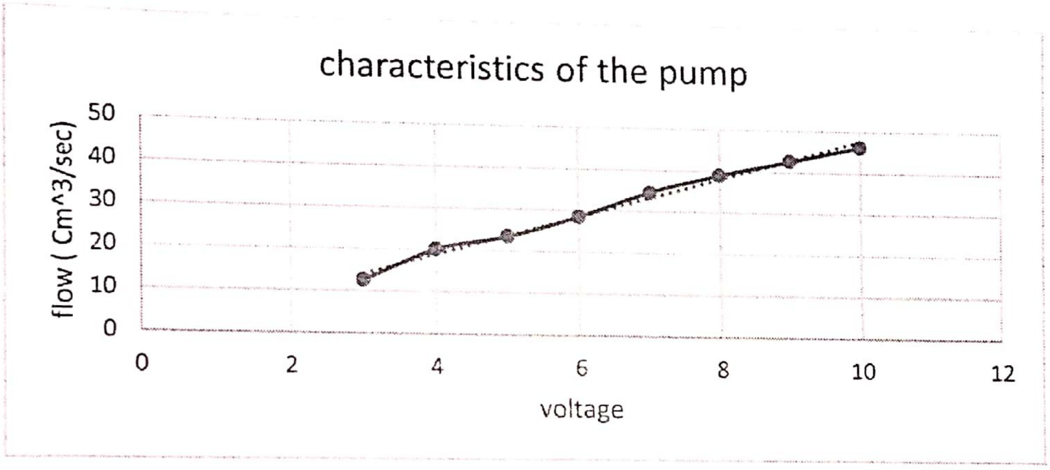


Figure 1

Part 2: ON -Off control of the level

Table 2:On-Off control level

Hysteresis%	**0**	**15**	**30**
set point	5	5	5
lower limit set point (cm)	4.8	3.5	2
up-raising time of level(sec)	3.42	34	64
upper limit set point(cm)	5.1	6.6	8.1
lowering time of the level(sec)	3.58	37	69

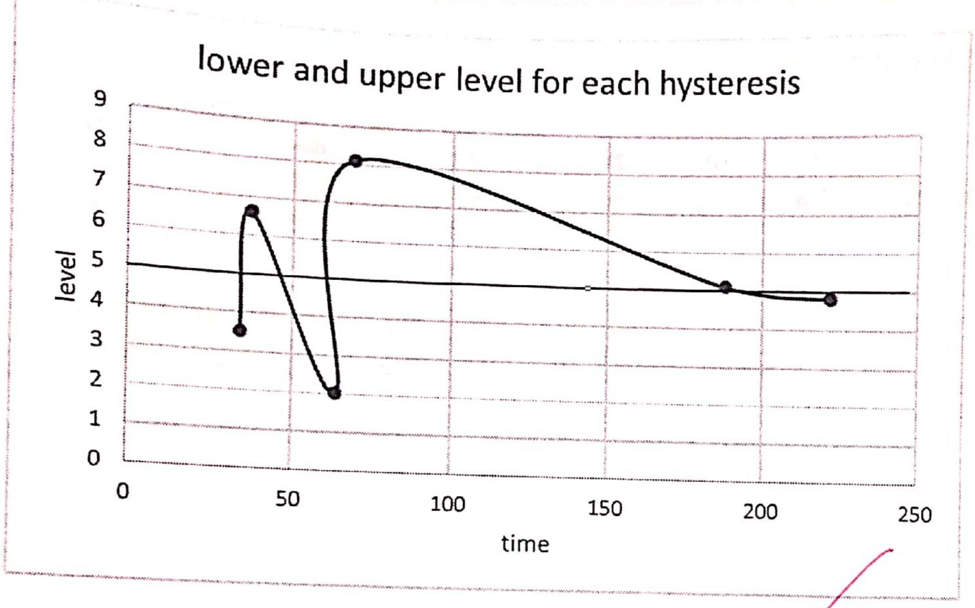
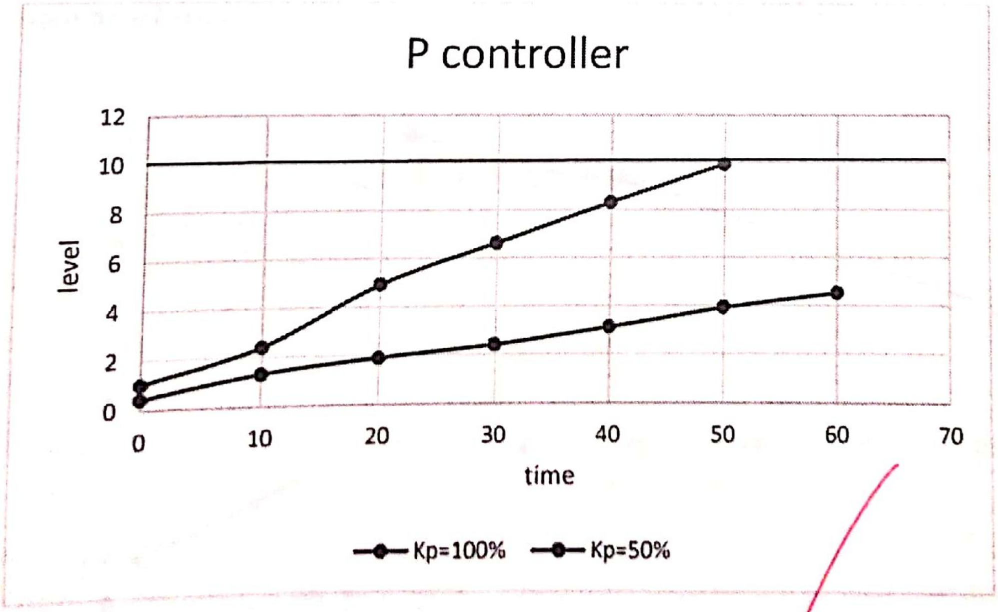


Figure 2: upper and lower limit

Part 3: P-controller of the level.

Table 3:P-controller set point (10v)

time	0	10	20	30	40	50	60
K_p=100%	1	2.4	4.9	6.6	8.3	9.9	9.9
K_p=50%	0.4	1.3	1.9	2.4	3.1	3.9	4.5



Part 4: PI-controller of the level.

Table 4:PI-controller

Time	**0**	**10**	**20**	**30**	**40**	**50**	**60**
K_p=100% Ki=100% τ1=1	0.4	2	3.4	4.5	5.5	6.2	6.8
K_p=100% ki=50% τ=2	0.4	1.8	2.5	3.2	3.9	4.2	4.8

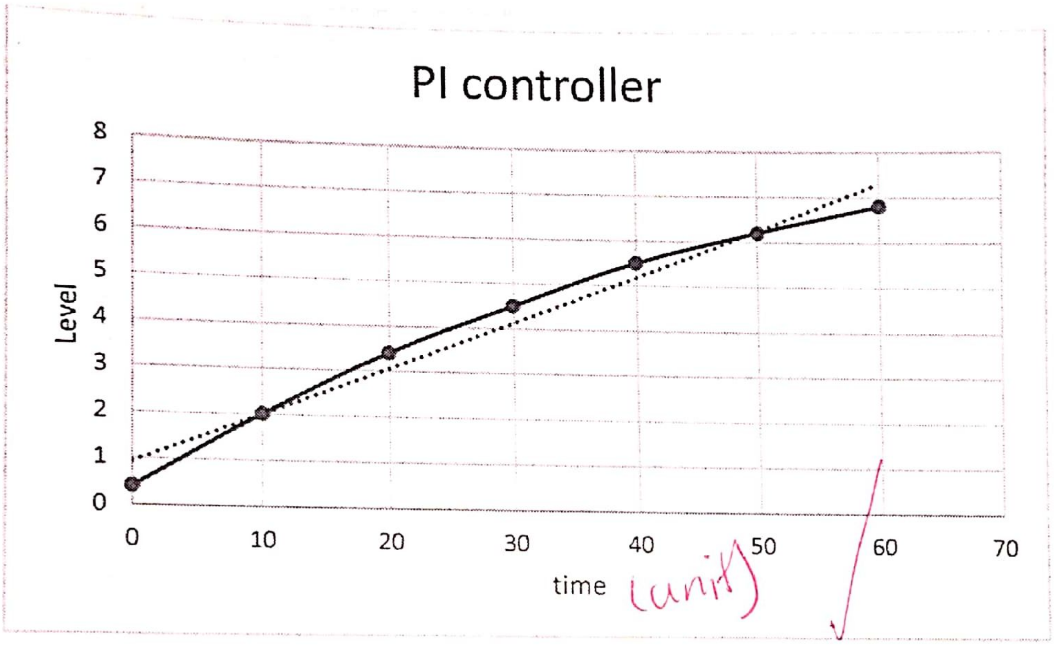


Figure 3:Kp=100% Ki=100% τ1=1

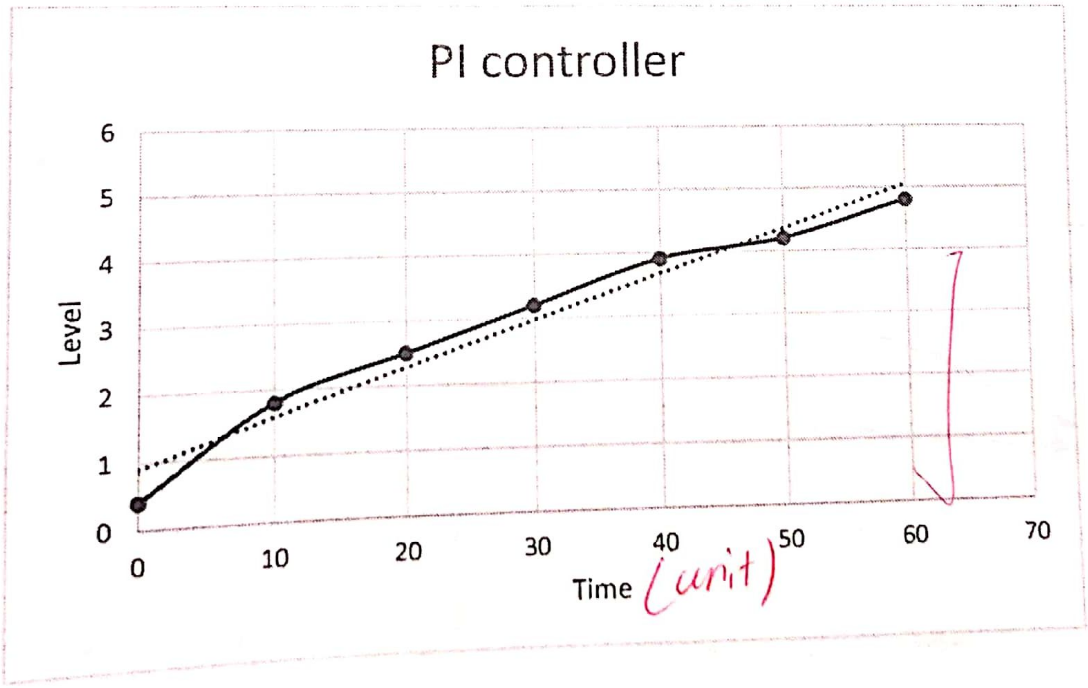
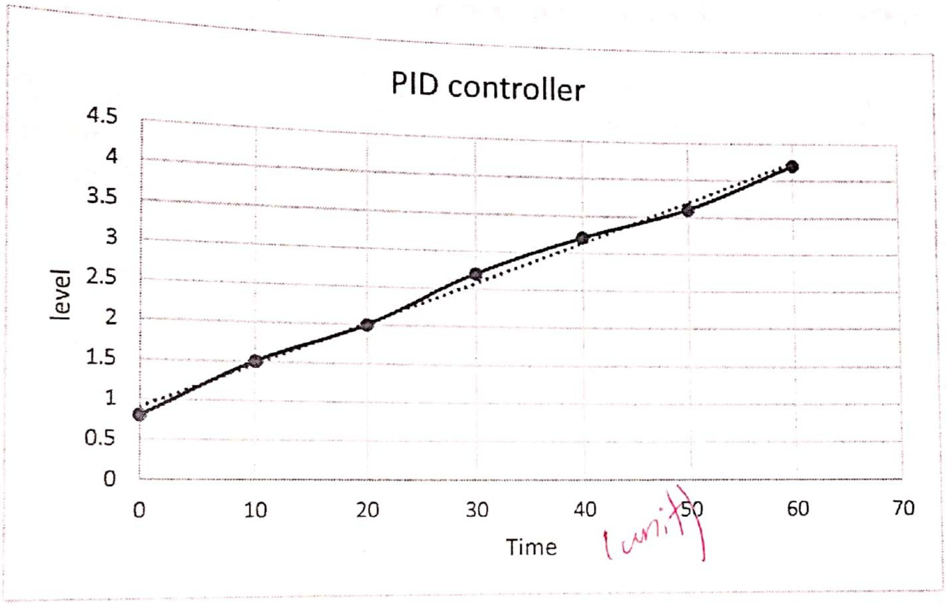


Figure 4:Kp=100% ki=50% τ=2

Part 4: PID-controller of the level.

Table 5:PID-controller

Time	**0**	**10**	**20**	**30**	**40**	**50**	**60**
Kp=100%, τi=1,τd=1	0.8	1.5	2	2.7	3.2	3.6	4.2
Kp=100%, τi=2,τd=0.5	0.5	1.2	2	2.4	3.1	3.7	4.1



(unit)

Figure 5:Kp=100%, τi=1,τd=1

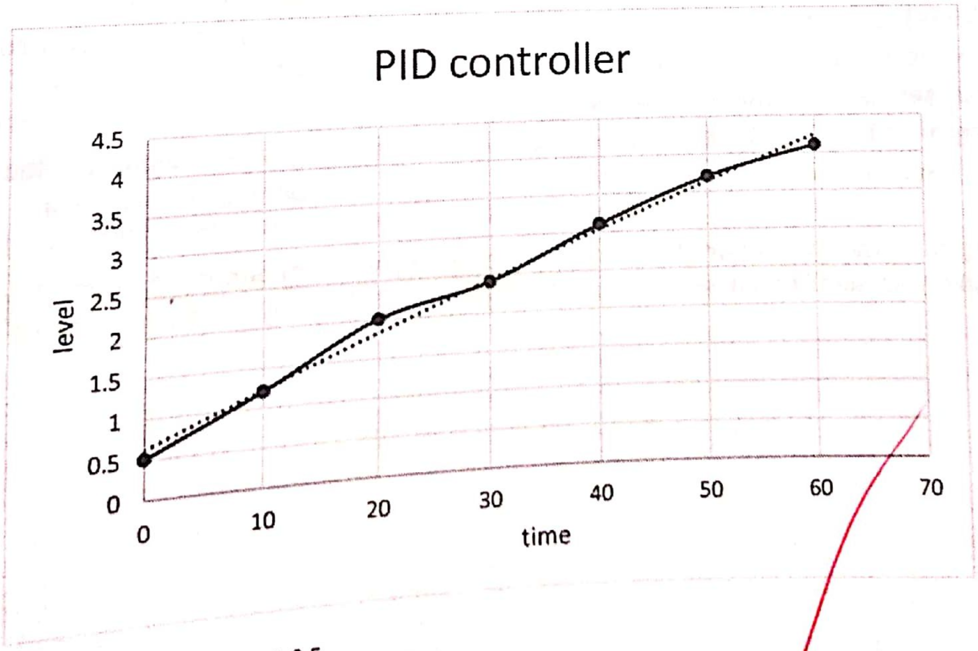


Figure 6:Kp=100%, τi=2,τd=0.5

Discussion

- First objective of this experiment is drawing the characteristic of the pump. The characteristic curve of a pump is the interaction of two variables that describe its performance:
    1. The Voltage.
    2. Volumetric flowrate: the quantity of fluid that goes through a section in a certain period of time.

  pump is a mechanical element that is driven by an electric motor, so as we see in figure one when the voltage is increase the quantity of fluid that increase.
  In addition, in every run the pump sucks up fluid in fixed volume (5cm^3) and from table number one we can notice that the increase of voltage the time to suction 5cm^3 will decrease.

- Second objective to study the effect of hysteresis on on-off control :
  The on-off control is the simplest form of a controller, which switches ON when the error is positive and switches OFF when the error is zero or negative. An on-off controller doesn't have intermediate states but only fully ON or fully OFF states. Due to the switching logic, an on-off controller is often called a bang-bang controller or a two-step controller.

  Hysteresis is the measurement of the difference in offset of the values generated by the transducer as it measures in a positive going direction, and the same values as the transducer measures back down toward zero (the negative going values).

  The higher the hysteresis value, the lower the switching frequency and the higher the overshoot. For our experiment, if the level is set to 5cm and the hysteresis percent is 15%, the on-off controller will switch OFF when the level is 6.6cm and switch ON when it is 3.5cm on the other hand when the hysteresis percent is 30%, OFF when the level is 8.1cm and switch ON when it is 2cm,also the rising and lowering time will increase according to increasing in hysteresis.

- Finally, understanding the theoretical aspect of the operation of closed loop system with proportional action(P), proportional-integral (PI), proportional-integral-derivative (PID):
  - proportional action(P): increasing the proportional gain will increase the speed of the control system response and decrease the offset, as we see in table 3 when Kc is 100% the controller to become closer to the set point in time less than when the Kc is 50%.
  - proportional-integral action (PI): Once P has been set to obtain a desired fast response, the integral term to decrease the offeset. Increasing the τ_i will increase the speed of the control system response.
  - proportional-integral-derivative action (PID): Increasing derivative term decreases overshoot and yields higher gain with stability but would cause the system to be highly sensitive to noise.

Conclusion

The characteristic curve of a pump is the interaction of two variables that describe its performance Voltage and Volumetric flowrate

When voltage increase the quantity of fluid increase and time to suction 5cm^3 will decrease.

An on-off controller doesn't have intermediate states but only fully ON or fully OFF states. often called a bang-bang controller or a two-step controller.

The higher the hysteresis value, the lower the switching frequency and the higher the overshoot.

When study the operation of closed loop system with deferent controller see that :

- proportional action(P): increasing the proportional gain will increase the speed of the control system response and decrease the offset
- proportional-integral action (PI): Increasing the τ_i will increase the speed of the control system response.
- proportional-integral-derivative action (PID): Increasing derivative term decreases overshoot and yields higher gain with stability but would cause the system to be highly sensitive to noise.

References

1. GEORGE STEPHANOPOULOS, "Chemical Process Control- An introduction into theory and practice- ", Department of Chemical Engineering-Massachusetts institute of Technology.

2. Seborg, Edgar, Mellichamp, Doyle, "Process Dynamics and Control", third edition.

3. Chemical Engineering Laboratory (4) Manual

Voltage	3	4	5	6	7	8	9	10
Volume	[illegible]							
Time	1:37	0:56	49	44	33	29	26	24
flow from soft (L/hr)	45	72	84	102	124	140	153	166

5cm.

Hys	0	15	30
setpoint	5	5	5
Lower Limit ~~lower limit~~ ~~upper rising time~~	4.8cm	3.5 cm	2 cm
upper limit rising time(s)	3.42(s)	34(s)	1:04 min
upper Limit	5.1	6.6	8.1
Lower time sec	~~4.34~~ 3.8 s	34 s	1:09 min.

✓

Time	0	10	20	30	40	50	60
kp=25%							
kp=50%	0.4	1.3	1.9	2.4	3.1	3.9	4.5
~~kp=75%~~							
kp=100%	1	2.4	4.9	6.6	8.3	9.9	9.9.

22/12/2021

Scanned with CamScanner

Time	0	10	20	30	40	50	60
kp = 100% KI = 100% JI = 1	~~2~~ 0.4	2	3.4	4.5	5.5	6.2	~~6.8~~ 6.8
JI = 2 Kp = 100% KI = 50%	0.4	~~2.1~~ 1.8	~~3.1~~ 2.5	3.2	3.9	4.2	4.8

J=

$J_d = \frac{k_d}{k_p}$

Time	0	10	20	30	40	50	60
JI = 1 Jd = 1 kp = 100%	0.8	1.5	2	2.7	3.2	3.6	4.2.
JI = 2 Jd = 0.5	0.5	~~2~~ 1.2	2	2.4	3.1	3.7	4.1

22/12/2021

Seen