



**Department of Chemical Engineering**

# Reaction Engineering Lab

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ChE-433 Manual

**Instructor:**

**Eng.Najem Alarwan**

**STUDENT NAME:**

**STUDENT NUMBER:**

**SEMESTER / YEAR:**

## EXPERIMENT #01 (RK-01)

### ISOTHERMAL OPERATION OF BATCH REACTOR

#### OBJECTIVE:

1. To determine the value of the rate constant during saponification of ethyl acetate
2. To demonstrate isothermal operation in batch reactor.

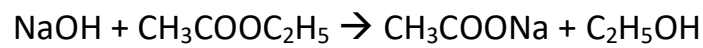
#### THEORITICAL BACKGROUND

A batch reactor is normally used for small scale operation, for testing new process that has not been fully developed, for producing very expensive product and for processes that is difficult to be run at continuous process.

Material balance done for batch reactors results in the following governing equation:

$$\frac{dC_A}{dt} = (-r_A) \quad (1)$$

The liquid phase reaction in this experiment is :



From stoichiometry of the above reaction, we obtain relation between concentration of sodium hydroxide (A) as function of conversion as follows :

$$C_A = C_{A0}(1 - x) \quad (2)$$

Assuming the reaction is pseudo first order reaction with respect to sodium hydroxide, one can easily get

$$-r_A = k \cdot C_A^2 \quad (3)$$

Substitute eq. (2) to (3) and later substitute for  $-r_A$  in eq. (1), one can eventually get

$$k \cdot t = \frac{C_{A0} - C_A}{C_{A0} \cdot C_A} \quad (4)$$

During the reaction, sodium hydroxide will dissociate into sodium ion and hydroxide ion while ethylacetate will also dissociate acetate ion and ethyl ion. Hydroxide ions will be bound to ethyl ions producing ethanol while acetate will be bound with sodium resulting in sodium acetate. The presence of hydroxide ions can be traced by measuring the conductivity of the solution. Thus, conversion of the reaction can be directly related to the conductivity by the following equation:

$$X = 1 - \frac{\Lambda_{\infty} - \Lambda}{\Lambda_{\infty} - \Lambda_0}$$

(5)

## DESCRIPTION OF THE EQUIPMENT

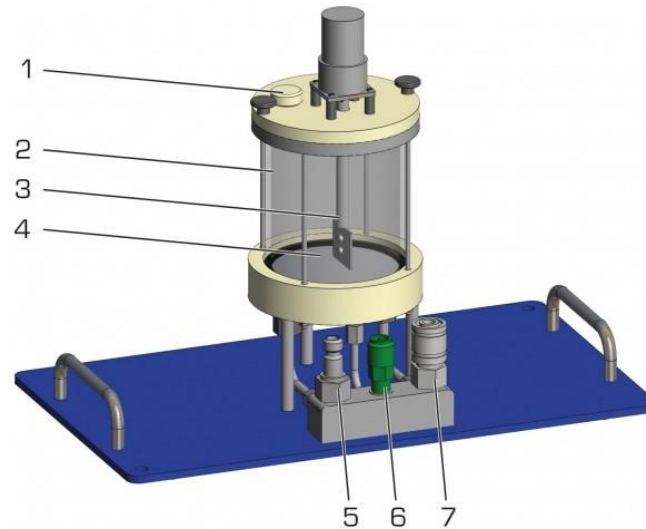


Figure 1. Batch Reactor (CE 310.04 of GUNT)

1. Hole for sensor for conductivity and temperature (included in CE 310), 2. stirred tank reactor, 3. stirrer, 4. Chambered bottom as heat exchanger, 5. water supply, 6. product drain, 7. water drain

## EXPERIMENTAL PROCEDURE

### 1. Solution Preparation

#### Dilution of ethyl acetate :

- Take 9.79 ml of ethyl acetate ( $\rho = 0.9 \text{ g/cm}^3$  ;  $M_w = 88.11 \text{ g/mol}$ ) to prepare 1000 mL of ethyl acetate 0.1 M.
- Dilute it until the total volume reach 1000 mL in a 1L-volumetric flask.
- Close the flask tightly and shake it rigorously until ethyl acetate and water are completely mixed.

#### Dilution of Sodium hydroxide :

- Take 4 g of sodium hydroxide ( $M_w = 40 \text{ g/mol}$ ) to prepare 1000 mL of sodium hydroxide 0.1 M.
- Dilute it until the total volume reach 1000 mL in a 1L-volumetric flask.
- Close the flask tightly and shake it rigorously until sodium hydroxide and water are completely mixed.

### 2. Batch reactor operational procedure.

- Switch the water circulator of CE 310 trainer to maintain the temperature at room temperature.

- b. Carefully introduce to the batch reactor (CE 310.04) 900 mL of 0.1 M NaOH solution.
- c. Observe for few minutes until the temperature of NaOH solution remains constant.
- d. Adjust the stirrer to a medium speed but do not switch it on yet.
- e. Carefully introduce to the reactor 90 mL of 0.1 M ethyl acetate.
- f. Start the stirrer and record the time.
- g. Record conductivity and temperature for  $\pm 30$  min.
- h. Repeat the experiment at new temperature (10 °C higher than room temperature)

## REFERENCES

Manual of CE310.04, GUNT

Fogler, H.S. , Elements of Chemical Reaction Engineering, 4<sup>th</sup> edition, 2007, Prentice Hall NY

## NOTATION

C	:	Concentration, kmol/m <sup>3</sup>
$\Lambda$	:	Conductivity, Siemens/cm
k	:	Reaction rate constant
r	:	Rate of reaction, s
t	:	Time, s
T	:	Temperature, K

## WORK SHEET

Students' Name and ID:

	ID #
	ID #
	ID #
	ID #

Temperature : \_\_\_\_\_ °C

Time Min : sec	Conductivity S/cm	Temperature °C	Time Min : sec	Conductivity S/cm	Temperature °C
0:00			5:00		
0:20			6:00		
0:40			7:00		
1:00			8:00		
1:20			10:00		
1:40			12:00		
2:00			14:00		
2:30			16:00		
3:00			20:00		
3:30			24:00		
4:00			28:00		
4:30			32:00		

Temperature : \_\_\_\_\_ °C

Time Min : sec	Conductivity S/cm	Temperature °C	Time Min : sec	Conductivity S/cm	Temperature °C
0:00			5:00		
0:20			6:00		
0:40			7:00		
1:00			8:00		
1:20			10:00		
1:40			12:00		
2:00			14:00		
2:30			16:00		
3:00			20:00		
3:30			24:00		
4:00			28:00		
4:30			32:00		

Task (must be included in the report) :

1. Determine initial concentration of NaOH solution
2. Convert conductivity data into concentration of NaOH
3. Plot equation (4) and comment on the plot!
4. Plot temperature vs time and comment on the plot!
5. Determine the reaction rate constant at the above two temperatures, determine also activation energy for this reaction and compare it with literature value.

## EXPERIMENT #02 (RK-02)

### ADIABATIC OPERATION OF BATCH REACTOR

#### OBJECTIVE:

3. To demonstrate adiabatic operation in batch reactor.
4. To compare the conversion achieved by isothermal and adiabatic operation.

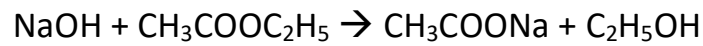
#### THEORITICAL BACKGROUND

A batch reactor is normally used for small scale operation, for testing new process that has not been fully developed, for producing very expensive product and for processes that is difficult to be run at continuous process.

Material balance done for batch reactors results in the following governing equation:

$$\frac{dC_A}{dt} = (-r_A) \quad (6)$$

The liquid phase reaction in this experiment is :



From stoichiometry of the above reaction, we obtain relation between concentration of sodium hydroxide (A) as function of conversion as follows :

$$C_A = C_{A0}(1 - x) \quad (7)$$

Assuming the reaction is pseudo first order reaction with respect to sodium hydroxide, one can easily get

$$-r_A = k \cdot C_A \quad (8)$$

Substitute eq. (2) to (3) and later substitute for  $-r_A$  in eq. (1), one can eventually get

$$\frac{\partial X}{\partial t} = -k(1 - X) \quad (9)$$

During the reaction, sodium hydroxide will dissociate into sodium ion and hydroxide ion while ethylacetate will also dissociate acetate ion and ethyl ion. Hydroxide ions will be bound to ethyl ions producing ethanol while acetate will be bound with sodium resulting in sodium acetate. The presence of hydroxide ions can be traced by measuring the conductivity of the solution. Thus, conversion of the reaction can be directly related to the conductivity by the following equation:

$$X = 1 - \frac{\Lambda_{\infty} - \Lambda}{\Lambda_{\infty} - \Lambda_0}$$

(10)

## DESCRIPTION OF THE EQUIPMENT

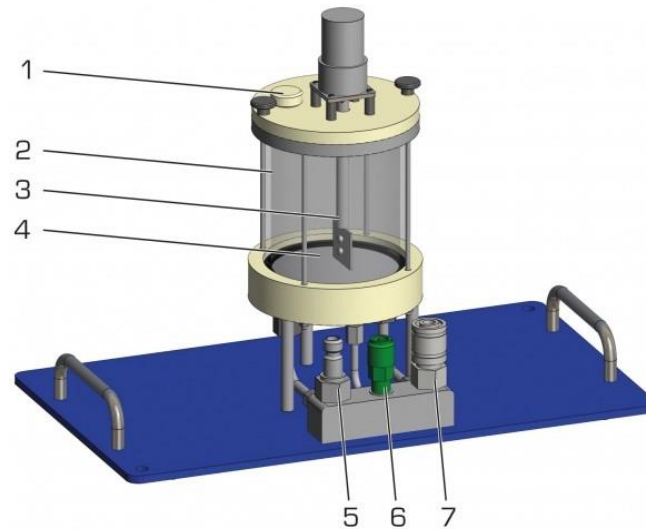


Figure 1. Batch Reactor (CE 310.04 of GUNT)

1. Hole for sensor for conductivity and temperature (included in CE 310), 2. stirred tank reactor, 3. stirrer, 4. Chambered bottom as heat exchanger, 5. water supply, 6. product drain, 7. water drain

## EXPERIMENTAL PROCEDURE

### 3. Solution Preparation

#### Dilution of ethyl acetate :

- d. Take 9.79 ml of ethyl acetate ( $\rho = 0.9 \text{ g/cm}^3$  ;  $M_w = 88.11 \text{ g/mol}$ ) to prepare 1000 mL of ethyl acetate 0.1 M.
- e. Dilute it until the total volume reach 1000 mL in a 1L-volumetric flask.
- f. Close the flask tightly and shake it rigorously until ethyl acetate and water are completely mixed.

#### Dilution of Sodium hydroxide :

- d. Take 4 g of sodium hydroxide ( $M_w = 40 \text{ g/mol}$ ) to prepare 1000 mL of sodium hydroxide 0.1 M.
- e. Dilute it until the total volume reach 1000 mL in a 1L-volumetric flask.
- f. Close the flask tightly and shake it rigorously until sodium hydroxide and water are completely mixed.



4. Batch reactor operational procedure.
  - a. Carefully introduce to the batch reactor (CE 310.04) 900 mL of 0.1 M NaOH solution.
  - b. Adjust the stirrer to a medium speed but do not switch it on yet.
  - c. Carefully introduce to the reactor 90 mL of 0.1 M ethyl acetate.
  - d. Start the stirrer and record the time.
  - e. Record conductivity and temperature for  $\pm 30$  min.

## REFERENCES

Manual of CE310.04, GUNT

Fogler, H.S. , Elements of Chemical Reaction Engineering, 4<sup>th</sup> edition, 2007, Prentice Hall NY

## NOTATION

C	:	Concentration, kmol/m <sup>3</sup>
$\Lambda$	:	Conductivity, Siemens/cm
k	:	Reaction rate constant
r	:	Rate of reaction, s
t	:	Time, s
T	:	Temperature, K

## WORK SHEET

Students' Name and ID:

	ID #
	ID #
	ID #
	ID #

Time Min : sec	Conductivity S/cm	Temperature °C	Time Min : sec	Conductivity S/cm	Temperature °C
0:00			5:00		
0:20			6:00		
0:40			7:00		
1:00			8:00		
1:20			10:00		
1:40			12:00		
2:00			14:00		
2:30			16:00		
3:00			20:00		
3:30			24:00		
4:00			28:00		
4:30			32:00		

Task (must be included in the report) :

- Determine initial concentration of NaOH solution
- Convert conductivity data into conversion of NaOH
- Plot temperature vs time and conversion vs time comment on the plot!
- Derive  $\frac{\partial T}{\partial t}$  for adiabatic operation of batch reactor! (Hint: refer to chapter 8 of Fogler)
- Using the experimental k obtained from RK-01 experiment, prepare the profile of the conversion and temperature with respect to time of this adiabatic operation and put the experimental result on the same plot. Comment on the result! (use polymath to solve coupled of differential equation, you may need physical properties for solving this task).

## EXPERIMENT #03 (RK-03)

### ADIABATIC OPERATION OF BATCH REACTOR

#### OBJECTIVE:

5. To determine the order and reaction rate constant for liquid phase in CSTR.
6. To study the effect of flow rate on the conversion of reactant.
7. To evaluate the time required to reach steady-state operation

#### THEORITICAL BACKGROUND

Continuous stirred tank reactor (CSTR) is one of continuous flow reactors that are normally operated at steady state. It is normally used for liquid phase reaction and assumed to be completely mixed. Hence, temperature, concentration and reaction rate inside CSTR are no time dependence and position dependence. Due to that independence, the temperature and concentration at the exit point are the same as those inside the reactor.

The liquid phase reaction in this experiment is:



Material balance done for unsteady state is as follows:

$$F_{AO} = F_{AO}(1 - X) + (-r_A)V + \frac{d(VC_A)}{dt} \quad (11)$$

From stoichiometry of the above reaction, we obtain relation between concentration of sodium hydroxide (A) as function of conversion as follows :

$$C_A = C_{A0}(1 - x) \quad (12)$$

Also residence time can be calculated as follows

$$\tau = \frac{C_{A0} - C_A}{(-r_A)} \quad (13)$$

Assuming the reaction rate is only depending on sodium hydroxide, one can easily get

$$-r_A = k \cdot C_A^n \quad (14)$$

Substitute eq. (2) to (3) and later substitute for  $-r_A$  in eq. (1), one can eventually get

$$\frac{\partial X}{\partial t} = -kC_{A0}^2(1 - X)^2 - \frac{F_{AO}}{VC_{A0}}X \quad (15)$$

During the reaction, sodium hydroxide will dissociate into sodium ion and hydroxide ion while ethylacetate will also dissociate acetate ion and ethyl ion. Hydroxide ions will be bound to ethyl ions producing ethanol while acetate will be bound with sodium resulting in sodium acetate. The presence of hydroxide ions can be traced by measuring the conductivity of the solution. Thus, conversion of the reaction can be directly related to the conductivity by the following equation:

$$X = 1 - \frac{\Lambda_{\infty} - \Lambda}{\Lambda_{\infty} - \Lambda_0} \quad (16)$$

### DESCRIPTION OF THE EQUIPMENT

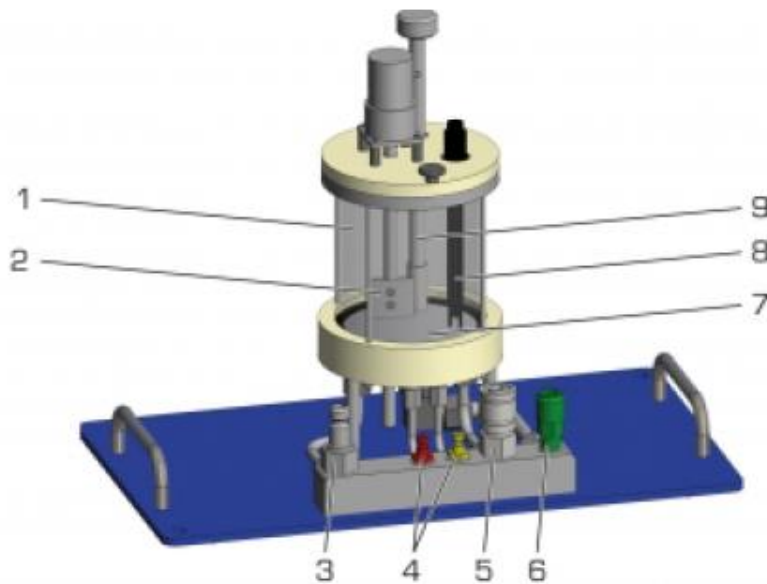


Figure 1. Batch Reactor (CE 310.01 of GUNT)

1. stirred tank reactor, 2. stirrer, 3. water supply, 4. reactants A/B supply, 5. water drain, 6. product drain, 7. chambered bottom as heat exchanger, 8. sensor for conductivity and temperature (included in CE 310), 9. height-adjustable overflow

### EXPERIMENTAL PROCEDURE

#### 5. Solution Preparation

##### Dilution of ethyl acetate :

- g. Take 39.16 ml of ethyl acetate ( $\rho = 0.9 \text{ g/cm}^3$ ;  $M_w = 88.11 \text{ g/mol}$ ) to prepare 4000 mL of ethyl acetate 0.1 M.
- h. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
- i. Stir it rigorously until ethyl acetate and water are completely mixed.

##### Dilution of Sodium hydroxide :

- g. Take 16 g of sodium hydroxide ( $M_w = 40 \text{ g/mol}$ ) to prepare 4000 mL of sodium hydroxide 0.1 M.
  - h. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
  - i. Stir it rigorously until sodium hydroxide and water are completely mixed.
6. CSTR operational procedure.
- a. Calibrate the actual flow rate of both pump needed in this experiment at speed scale of 40 and 80.
  - b. Measure the height of the liquid level in CSTR (inside diameter of CSTR is 100 mm).
  - c. Connect the correct chemical hoses from the pumps to the tank.
  - d. Insert conductivity measuring sensor in the measuring opening on the lid and connect the stirrer.
  - e. Adjust the overflow on the tank such that the measuring sensor is immersed approximately 50 mm in the liquid with the tank filled.
  - f. Set required temperature for the heating regulator to 40oC and switch on the heater.
  - g. Switch on the chemical pumps and adjust both to the same flow rate approximately 80:80.
  - h. When the liquid level reaches the overflow, switch on the stirrer and adjust to a medium speed.
  - i. At every 20 seconds measure the conductivity and temperature until it reach steady state.
  - j. Reduce the flow rate to 40:40
  - k. At every 20 seconds measure the conductivity and temperature until it reach steady state.
  - l. increase the flow rate to 80:80
  - m. At every 20 seconds measure the conductivity and temperature until it reach steady state.
  - n. Stop the reactor and clean it.

## REFERENCES

Manual of CE310.01, GUNT

Fogler, H.S. , Elements of Chemical Reaction Engineering, 4<sup>th</sup> edition, 2007, Prentice Hall NY

## NOTATION

C	:	Concentration, $\text{kmol/m}^3$
$\Lambda$	:	Conductivity, Siemens/cm
k	:	Reaction rate constant
r	:	Rate of reaction, s
t	:	Time, s
T	:	Temperature, K



# WORK SHEET

Students' Name and ID:

	ID #
	ID #
	ID #
	ID #

80:80			40:40			80:80		
Time	Conductivity	Temperature	Time	Conductivity	Temperature	Time	Conductivity	Temperature
Min : sec	S/cm	°C	Min : sec	S/cm	°C	Min : sec	S/cm	°C
0:00			0:00			0:00		
0:30			0:30			0:30		
1:30			1:30			1:30		
2:00			2:00			2:00		
2:30			2:30			2:30		
3:00			3:00			3:00		
3:30			3:30			3:30		
4:00			4:00			4:00		
5:00			5:00			5:00		
6:00			6:00			6:00		
7:00			7:00			7:00		

Task (must be included in the report) :

11. Convert conductivity data into conversion of NaOH.
12. Linearize equation # 4 and get the value of k and n and use experimental data for that purpose. In order to do that  $(-r_A)$  must be calculated first from equation #3.
13. Plot temperature vs time for all flow rate change in one graph! Do the same for conversion vs time. Comment on the plot.
14. Determine the time required to reach steady state experimentally from the above graph (step #4) for each flow rate.
15. Determine the time required to reach steady state numerically by solving equation #5.
16. Plot conversion vs time experimentally and theoretically in one graph, and comment on the plot.



## EXPERIMENT #04 (RK-04)

### OPERATION OF PLUG FLOW REACTOR

#### OBJECTIVE:

8. To determine the order and reaction rate constant for liquid phase in PFR.
9. To study the effect of flow rate on the conversion of reactant.

#### THEORITICAL BACKGROUND

Plug Flow Reactor (PFR) is one of continuous flow reactors that are normally operated at steady state. It is normally used for gas phase reaction but it can also be used for liquid phase reaction. In PFR, there is no radial variation in terms of temperature and concentration. The reactants are consumed continuously through the reactor in axial direction.

The liquid phase reaction in this experiment is:



Material balance done for steady state is as follows:

$$F_A = F_A + dF_A + (-r_A)dV \quad (17)$$

From stoichiometry of the above reaction, we obtain relation between concentration of sodium hydroxide (A) as function of conversion as follows :

$$C_A = C_{A0}(1 - x) \quad (18)$$

By taking

$$\tau = \frac{V}{v} \quad (19)$$

One can modify eq. (1) into

$$\tau = - \int_{C_{A0}}^{C_A} \frac{dC_A}{-r_A} \quad (20)$$

assuming the reaction rate is only depending on sodium hydroxide, one can easily get

$$-r_A = k \cdot C_A^n \quad (21)$$

During the reaction, sodium hydroxide will dissociate into sodium ion and hydroxide ion while ethylacetate will also dissociate acetate ion and ethyl ion. Hydroxide ions will be bound to ethyl ions producing ethanol while acetate will be bound with sodium resulting in sodium acetate. The presence of hydroxide ions can be traced by measuring the conductivity of the solution. Thus, conversion of the reaction can be directly related to the conductivity by the following equation:

$$X = 1 - \frac{\Lambda_{\infty} - \Lambda}{\Lambda_{\infty} - \Lambda_0} \quad (22)$$

### DESCRIPTION OF THE EQUIPMENT

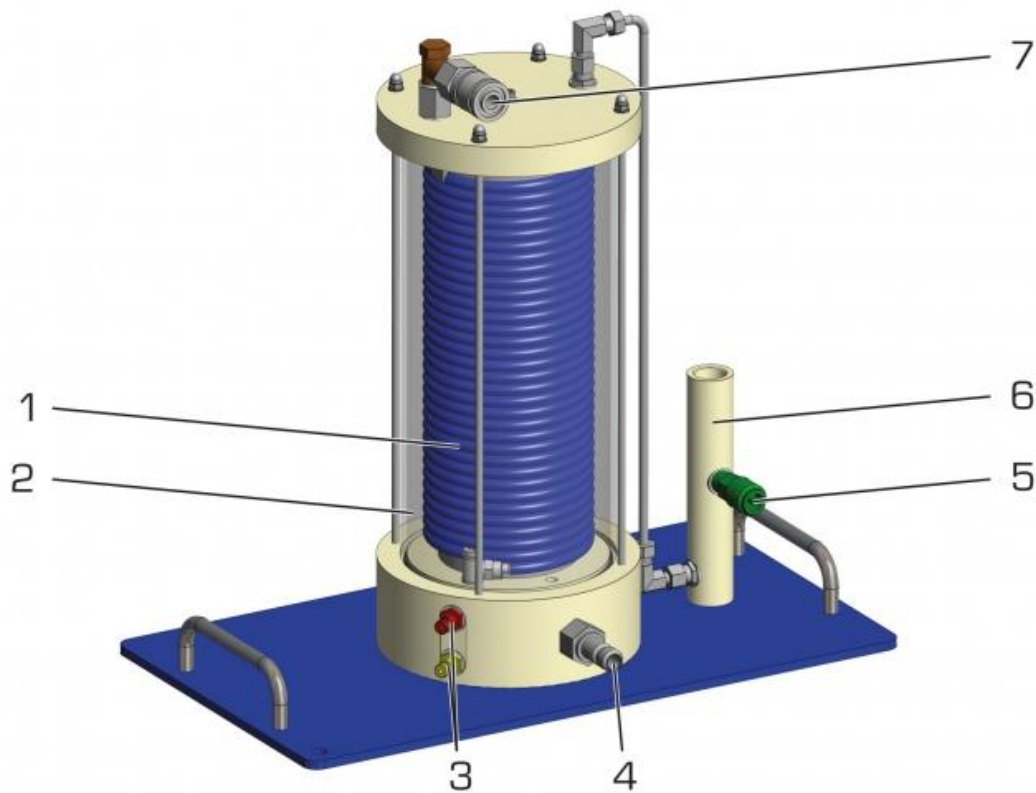


Figure 1. Tubular Reactor (CE 310.02 of GUNT)

1. tubular reactor, 2. double jacket, 3. reactants A/B supply, 4. water supply, 5. product drain, 6. sleeve for sensor for conductivity and temperature

### EXPERIMENTAL PROCEDURE

7. Solution Preparation

Dilution of ethyl acetate :

- j. Take 39.16 ml of ethyl acetate ( $\rho = 0.9 \text{ g/cm}^3$ ;  $M_w = 88.11 \text{ g/mol}$ ) to prepare 4000 mL of ethyl acetate 0.1 M.
- k. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
- l. Stir it rigorously until ethyl acetate and water are completely mixed.

Dilution of Sodium hydroxide :

- j. Take 16 g of sodium hydroxide ( $M_w = 40 \text{ g/mol}$ ) to prepare 4000 mL of sodium hydroxide 0.1 M.
  - k. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
  - l. Stir it rigorously until sodium hydroxide and water are completely mixed.
8. PFR operational procedure.
- a. Calibrate the actual flow rate of both pump needed in this experiment at speed scale of 20; 40 and 80.
  - b. Connect the correct chemical hoses from the pumps to the tank.
  - c. Insert conductivity measuring sensor at the outlet of PFR.
  - d. Set required temperature for the heating regulator to  $40^\circ\text{C}$  and switch on the heater.
  - e. Switch on the chemical pumps and adjust both to the same flow rate approximately 20:20.
  - f. At specific interval (as provided in the log sheet) measure the conductivity and temperature until it reach steady state.
  - g. Repeat step e-f for the flow rate to 40:40 and 80:80

**REFERENCES**

Manual of CE310.02, GUNT

Fogler, H.S. , Elements of Chemical Reaction Engineering, 4<sup>th</sup> edition, 2007, Prentice Hall NY

**NOTATION**

C	:	Concentration, $\text{kmol/m}^3$
$\Lambda$	:	Conductivity, Siemens/cm
k	:	Reaction rate constant
r	:	Rate of reaction, s
t	:	Time, s
T	:	Temperature, K

# WORK SHEET

Students' Name and ID:

	ID #
	ID #
	ID #
	ID #

20:20			40:40			80:80		
Time Min : sec	Conductivity S/cm	Temperature °C	Time Min : sec	Conductivity S/cm	Temperature °C	Time Min : sec	Conductivity S/cm	Temperature °C
0:00			0:00			0:00		
0:30			0:30			0:30		
1:30			1:30			1:30		
2:00			2:00			2:00		
2:30			2:30			2:30		
3:00			3:00			3:00		
3:30			3:30			3:30		
4:00			4:00			4:00		
5:00			5:00			5:00		
6:00			6:00			6:00		
7:00			7:00			7:00		

Task (must be included in the report) :

17. Convert conductivity data into conversion of NaOH.
18. Find from the literature what is the order and  $k$  of reaction.
19. Substitute the rate law (as you obtain from the literature) to eq. 5 and solve the integral.
20. Evaluate both theoretical and experimental values of conversions for each run.
21. Plot experimental conversion vs space time data and compare it with theoretical prediction.

## EXPERIMENT #05 (RK-05)

### OPERATION OF CSTR in SERIES

#### OBJECTIVE:

To study the effect of flow rate on the overall conversion of reactant in steady state operation of CSTR in series.

#### THEORITICAL BACKGROUND

CSTR in series is one of configuration of reactors that performs between single CSTR and PFR in terms of volume required to achieve the same conversion.

The liquid phase reaction in this experiment is:



Material balance done for steady state for first reactor is as follows:

$$F_{A0} = F_{A1} + (-r_A)_1 V_1 \quad (23)$$

From stoichiometry of the above reaction, we obtain relation between concentration of sodium hydroxide (A) as function of conversion as follows :

$$C_A = C_{A0}(1 - x) \quad (24)$$

By taking

$$\tau = \frac{V}{v} \quad (25)$$

Assuming the reaction rate is only depending on sodium hydroxide, one can easily get

$$-r_A = k \cdot C_A^n \quad (26)$$

Substitute equation (4) and (2) to equation (1) and solve for t will give us

$$\tau_1 = \frac{x_1}{k C_{A0}^{n-1} (1-x_1)^n} \quad (27)$$

With same approach one will get residence time for second and third reactors as follows

$$\tau_2 = \frac{x_2 - x_1}{k C_{A0}^{n-1} (1-x_2)^n} \quad (6)$$

$$\tau_3 = \frac{x_3 - x_2}{kC_{A0}^{n-1}(1-x_3)^n} \quad (7)$$

During the reaction, sodium hydroxide will dissociate into sodium ion and hydroxide ion while ethylacetate will also dissociate acetate ion and ethyl ion. Hydroxide ions will be bound to ethyl ions producing ethanol while acetate will be bound with sodium resulting in sodium acetate. The presence of hydroxide ions can be traced by measuring the conductivity of the solution. Thus, conversion of the reaction can be directly related to the conductivity by the following equation:

$$X = 1 - \frac{\Lambda_{\infty} - \Lambda}{\Lambda_{\infty} - \Lambda_0} \quad (8)$$

### DESCRIPTION OF THE EQUIPMENT

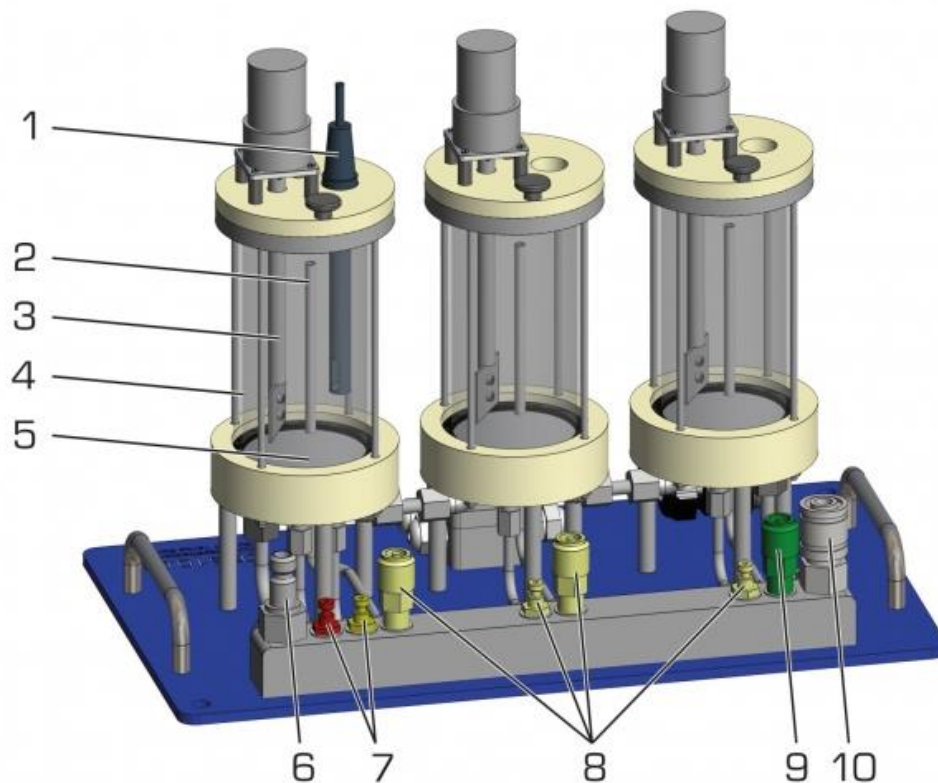


Figure 1. Tubular Reactor (CE 310.02 of GUNT)

1. sensor for conductivity and temperature, 2. overflow, 3. stirrer, 4. stirred tank, 5. chambered bottom as heat exchanger, 6. water supply, 7. reactants A/B supply, 8. intermediate delivery, 9. product drain, 10. water drain

## EXPERIMENTAL PROCEDURE

### 9. Solution Preparation

#### Dilution of ethyl acetate :

- m. Take 39.16 ml of ethyl acetate ( $\rho = 0.9 \text{ g/cm}^3$  ;  $M_w = 88.11 \text{ g/mol}$ ) to prepare 4000 mL of ethyl acetate 0.1 M.
- n. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
- o. Stir it rigorously until ethyl acetate and water are completely mixed.

#### Dilution of Sodium hydroxide :

- m. Take 16 g of sodium hydroxide ( $M_w = 40 \text{ g/mol}$ ) to prepare 4000 mL of sodium hydroxide 0.1 M.
- n. Dilute it until the total volume reach 4000 mL in a 4L-beaker.
- o. Stir it rigorously until sodium hydroxide and water are completely mixed.

### 10. CSTR in series operational procedure.

- a. Calibrate the actual flow rate of both pump needed in this experiment at speed scale of 40 and 80.
- b. Connect the correct chemical hoses from the pumps to the tank.
- c. Insert conductivity measuring sensor at the CSTR.
- d. Switch on the chemical pumps and adjust both to the same flow rate approximately 40:40.
- e. At specific interval (as provided in the log sheet) measure the conductivity and temperature until it reach steady state.
- f. Repeat step d-e for the flow rate to 80:80

## REFERENCES

Manual of CE310.03, GUNT

Fogler, H.S. , Elements of Chemical Reaction Engineering, 4<sup>th</sup> edition, 2007, Prentice Hall NY

## NOTATION

C	:	Concentration, $\text{kmol/m}^3$
$\Lambda$	:	Conductivity, Siemens/cm
k	:	Reaction rate constant
r	:	Rate of reaction, s
t	:	Time, s
T	:	Temperature, K



## WORK SHEET

Students' Name and ID:

	ID #
	ID #
	ID #
	ID #

	40:40				80:80		
Time	Conductivity of Tank #i			Time	Conductivity of Tank #i		
Min : sec	S/cm			Min : sec	S/cm		
0:00	1	2	3	0:00	1	2	3
0:30				0:30			
1:00				1:00			
2:00				2:00			
3:00				3:00			
4:00				4:00			
6:00				6:00			
8:00				8:00			
10:00				10:00			
13:00				13:00			
16:00				16:00			
20:00				20:00			

Task (must be included in the report) :

22. Convert conductivity data into conversion of NaOH.
23. Find from the literature what is the order and k of reaction.
24. Evaluate both theoretical and experimental values of conversions for each run.
25. Plot experimental conversion vs space time for each CSTR and compare it with theoretical prediction.