The University of Jordan

School of Engineering

Department of Chemical Engineering

Chemical Engineering Laboratory (4) (0905562)

Section no. (1)

Experiment no. (1)

Continuous Stirred Tank Reactor

Short Report

Date of Submission: 10th December 2023

Student Name	Registration #
Sedra Nibal Al-Burghili	0191293
Nour Ahmad Kharisat	0194083
Donia Majdi Khalil	0197045
Sura Mohammad Froukh	0197130
Lana Mamoon Abdelnabi	0198593

Instructor: Eng. Nariman Al-Dahleh

ABSTRACT

Continuous Stirred Tank Reactor CSTR is a type of chemical reactor system used in industrial processes for the continuous mixing of reactants to achieve a consistent and uniform reaction. The design and operation of CSTRs depend on factors such as reaction kinetics, heat transfer, and mass transfer within the reactor. In a CSTR, reactants are continuously fed into a tank or reactor vessel, and products are continuously withdrawn.

In this experiment ethyl acetate and sodium hydroxide should be continuously fed into the reactor. Also, ethanol and sodium acetate, should be continuously withdrawn from the reactor. Due to determine the kinetics and reaction rate constant for the irreversible reaction. The reaction rate constant and order of reaction for the irreversible reaction are determined, and their values are 0.949(L.s/mol), 2.43 respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

RESULTS

Tables:

Table 1:Given Data.

Titrants	Concentration (M)
Concentration of HCL	0.03
Concentration of NaOH	0.03

Table 2: calculated Initial Concentration.

Volume of NaOH sample	10.00 ml
Volume of HCl needed for titration	11.80 ml
Volume of ethyl acetate sample	10.00 ml
Volume of NaOH added	30.00 ml
Volume of HCl needed for titration	12.00 ml
Volume of reactant NaOH	18.00 ml
Initial concentration of reactant ethyl acetate	0.054 M
Initial concentration of NaOH	0.0354 M

Table 3: Experimental and calculated data for CSTR.

Runs	Run 1	Run2	Run3
Flow rate of ethyl acetate(cm^3/sec)	7.00	8.00	6.00
Flow rate of sodium hydroxide (cm^3/sec)	7.00	6.00	8.00
Volume flow rate of Reactant (L/min)	0.84	0.84	0.84
τ (min)	3.21	3.21	3.21
Residence time (min)	16.07	16.07	16.07
Volume of NaOH (ml)	13.80	15.50	13.50
Flow rate of ethyl acetate (mol/s)	0.000378	0.000432	0.000324
Flow rate of NaOH (mol/s)	0.000248	0.000212	0.000283
Volume of HCl excess (ml)	13.80	15.50	13.50
Volume of excess sample of HCL (ml)	20.00	20.00	20.00
Volume of reacted HCl	6.20	4.50	6.50
Volume of sample from reactor	10.00	10.00	10.00
C_{NaOH} **(M)**	0.0186	0.0135	0.0195
Conversion (%)	47.5	61.80	44.92
Rate of reaction ($-r_A$)	4.36×10^{-5}	4.87×10^{-5}	4.71×10^{-5}
Ratio of flowrate of Sodium Hydroxide to Ethyl Acetate 'θ'	1.52	2.03	1.14
Reaction rate constant $\left(\frac{L}{mol.s}\right)$	0.0192	0.0210	0.0144

Table 4 : finding the order and rate of reaction constant using Method of Excess.

Rate of reaction "-rA"	C_{NaOH} **(M)**	**ln(-r**$_A$**)**	**ln(**C_{NaOH}**)**
1.00	1.0000	0.00	0.00
$\mathbf{4.36 \times 10^{-5}}$	0.0186	-10.04	-3.98
$\mathbf{4.87 \times 10^{-5}}$	0.0135	-9.93	-4.31
$\mathbf{4.71 \times 10^{-5}}$	0.0195	-9.96	-3.93
Order of the reaction			
2.43			
Intercept	**Reaction rate constant** $\left(\frac{L}{mol.s}\right)$		
-0.0513	0.949		
$-r_A = 0.949[NaOH]^{2.43}$			

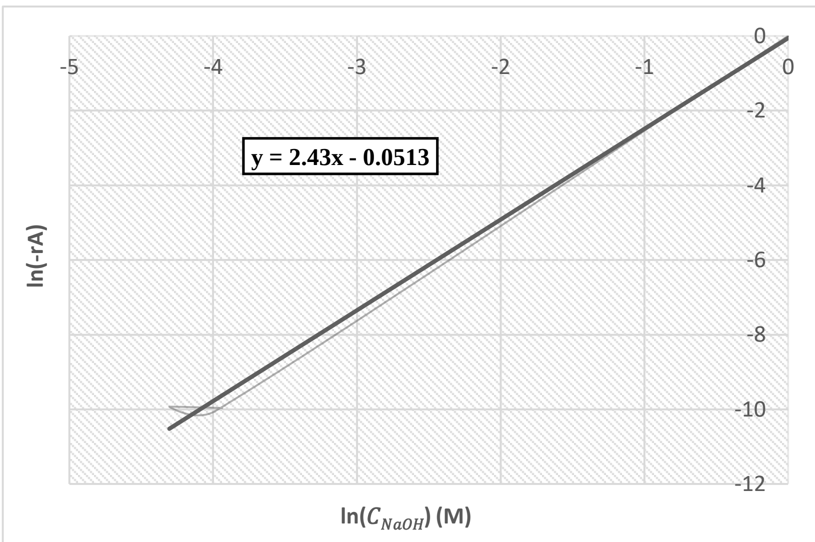

Figure 1: ln(-r$_A$) vs ln (C_{NaOH}) to calculate the orderof reaction and reaction rate constant.

DISCUSSION

The experimental results obtained from the Continuous Stirred Tank Reactor (CSTR) experiment are presented in Table 3. The experiment was conducted with a constant space time of 3.21 minutes and a residence time of 16.07 minutes, ensuring consistent volume and total flow rate for each run.

In Run 1, the flow rate of Sodium hydroxide and Ethyl Acetate was maintained at 7.00 cm^3/sec, resulting in equal flow rates for both components. The final concentration of NaOH was determined to be 0.0186 M, corresponding to a conversion of 47.5%. The rate of the reaction for this run was measured as 4.36×10^{-5}, with the unit of the rate unspecified. The rate of reaction constant specific to Run 1 was found to be 0.0192, with the unit also unspecified. The ratio of the flow rate of Sodium Hydroxide to Ethyl Acetate, denoted as 'θ', was calculated as 1.52.

In Run 2, the flow rate of Sodium hydroxide was 6.00 cm^3/sec, while the flow rate of Ethyl Acetate was 8.00 cm^3/sec. The final concentration of NaOH was determined to be 0.0135 M, resulting in a conversion of 61.8%. The rate of the reaction for this run was measured as $4.87 \times 10^{-5}$with the unit unspecified. The rate of reaction constant specific to Run 2 was calculated as 0.0210, again with the unit unspecified. The ratio of the flow rate of Sodium Hydroxide to Ethyl Acetate, denoted as 'θ', was found to be 2.03.

In Run 3, the flow rate of Sodium hydroxide was 8.00 cm^3/sec, while the flow rate of Ethyl Acetate was 6.00 cm^3/sec. The final concentration of NaOH was measured as 0.0195 M, leading to a conversion of 44.92%. The rate of the reaction for this run was determined to be 4.71×10^{-5}, with the unit unspecified. The rate of reaction constant specific to Run 3 was calculated as 0.0144, also with the unit unspecified. The ratio of the flow rate of Sodium Hydroxide to Ethyl Acetate, denoted as 'θ', was found to be 1.14.

It is evident from the data in Table 3 that the highest conversion rate was achieved in Run 2, given the specified flow rates. However, it should be noted that Sodium hydroxide (NaOH) is the primary reactant in this experiment. As observed, a decrease in the flow rate of NaOH relative to Ethyl Acetate resulted in an increased conversion rate. This can be attributed to a higher concentration of NaOH being available for the reaction, thereby promoting a more significant conversion.

Figure 1 illustrates the relationship between the rate of reaction and the concentration of NaOH on a log-log scale. The plot was analyzed to determine the rate order and reaction constant using the method of excess. The slope of the plot was calculated to be 2.43, indicating the order of the reaction.

Some possible sources of experimental errors could include inaccuracies in the measurement of the NaOH concentration. The measurements may have been affected by imprecise techniques or equipment limitations.

The intercept of the plot corresponds to the negative natural logarithm of the rate constant. Inverting the natural logarithm yields the rate reaction constant, which was determined to be 0.949 L/(mol·s).

CONCLUSION AND RECOMMENDATIONS

- A continuous stirred tank reactor is a vessel where the reactants fed to it and the products flow out from it continuously, and it is continuously stirred to achieve a uniform concentration through the vessel.
- Reaction performed in a continuous stirred tank needs 5τ to reach steady state.
- Total flow rate of reactants is maintained at a constant value in order to have the same residence time for each run.
- Increasing the volumetric flow rate of ethyl acetate has a bigger effect on increasing the reaction conversion relative to sodium hydroxide, since ethyl acetate have higher initial concentration.
- The rate of reaction increases by increasing the conversion. However, the reaction rate constant remains approximately unchanged since it’s a function of temperature and not the reactants concentration.
- The reaction needs a long time to achieve completion since ethyl acetate is a weak acid.
- The experimental reaction order is higher than true reaction order due to human errors such as inaccurate titration, or instrumental errors such as defect in inlet flow valves.

REFERENCES

1) Chemical Engineering Laboratory (4) Manual Sheet. (2022). 1st ed. University of Jordan School of Engineering Department of Chemical Engineering.
2) H. Scott Fogler (2006). Elements of Chemical Reaction Engineering. Prentice Hall.

APPENDICES

I. Sample of Calculation

Determine the kinetics and reaction rate constant of the essentially irreversible reaction between ethyl acetate and sodium hydroxide:

$$CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$$
$$NaOH + HCl \longrightarrow NaCl + H_2O$$

$\text{Conc. of HCL} = 0.03$
$\text{Conc. of NaOH} = 0.03$
$\text{Volume of NaOH sample} = 10 \text{ ml}$
$\text{Volume of HCL sample} = 11.8 \text{ ml}$
$\text{Volume of ethyl acetate sample} = 10 \text{ ml}$
$\text{Volume of NaOH added} = 30\text{ml}$
$\text{Volume of HCL needed for titration} = 12 \text{ ml}$

Volume of reactant NaOH

$$= \text{Volume of NaOH added} - \text{Volume of HCL needed for titration}$$
$$= 30 - 12 = 18 \text{ ml}$$

$$(M * V)_{\text{NaOH}} = (M * V)_{\text{ethyl acetate}}$$

$$\text{Initial conc. of ethyl acetate} = \frac{\text{Conc. of NaOH} * \text{Volume of NaOH}}{\text{Volume of ethyl acetate}} = \frac{0.3 * 18}{10}$$
$$= 0.054 \text{ M}$$

$$(M * V)_{\text{NaOH}} = (M * V)_{\text{HCl}}$$

$$\text{Initial conc. of NaOH} = \frac{\text{Conc. of HCl} * \text{Volume of HCl}}{\text{Volume of NaOH}} = \frac{0.3 * 11.8}{10} = 0.0354$$

<u>Sample of Calculations for The First Run:</u>

$\text{Flow rate of ethyl acetate} = 7 \text{ cm}^3/\text{sec}$
$\text{Flow rate of NaOH} = 7 \text{ cm}^3/\text{sec}$
$\text{Volume of NaOH} = 13.8 \text{ ml}$
$\text{Volume of excess sample of HCl} = 20 \text{ ml}$
$\text{Volume of sample from reactor} = 10 \text{ ml}$

Volume flow rate of Reactant

$$= \frac{(\text{Flow rate of ethyl acetate} + \text{Flow rate of NaOH}) * 60}{1000}$$
$$= \frac{(7 + 7) * 60}{1000} = 0.84(\text{L/min})$$

$$\tau = \frac{2.7}{\text{Volume flow rate of Reactant}} = \frac{2.7}{0.84} = 3.21(\text{min})$$

$$\text{Residence time} = 5 * \tau = 16.07\ (\text{min})$$

Flow rate of ethyl acetate

$$= \frac{\text{Initial conc. of ethyl acetate} * \text{Flow rate of ethyl acetate}}{1000}$$

$$= \frac{.054 * 7}{1000} = 0.000378(\text{mol/s})$$

$$\text{Flow rate of NaOH} = \frac{\text{Initial conc. of NaOH} * \text{Flow rate of NaOH}}{1000} = \frac{.0357 * 7}{1000}$$

$$= 0.0002478\ \text{mol/s}$$

$$\text{Volume of reacted HCl} = \text{Volume of excess sample of HCl} - \text{Volume of NaOH}$$

$$= 20 - 13.8 = 6.2\ \text{ml}$$

$$\text{Final conc of NaOH} = \frac{\text{Volume of reacted HCl} * \text{Conc. of HCl}}{\text{Volume of sample from reactor}} = \frac{6.2 * 0.03}{10}$$

$$= 0.0186\ \text{M}$$

<u>Conversion (X):</u>

$$X = \frac{\text{Initial conc. of NaOH} - \text{Final conc of NaOH}}{\text{Initial conc. of NaOH}} = \frac{0.0345 - 0.0186}{0.0354} = 0.4745$$

<u>Reaction rate ($-r_A$):</u>

$$-r_A = \frac{X * \text{Flow rate of NaOH}}{2.7} = \frac{0.04745 * 0.0002478}{2.7} = 4.355 * 10^{-5}(\text{mol/L} \cdot \text{s})$$

<u>Ratio of flowrate of Sodium Hydroxide to Ethyl Acetate (θ):</u>

$$\theta = \frac{\text{Flow rate of ethyl acetate}}{\text{Flow rate of NaOH}} = \frac{0.000378}{0.0002478} = 1.525 \frac{\text{mol ethyl acetate/s}}{\text{mol NaOH/s}}$$

<u>Reaction Rate constant (k):</u>

$$k = \frac{-r_A}{(\text{initial conc. of NaOH})^2 * (1 - X) * (\theta - X)}$$

$$= \frac{4.355 * 10^{-5}}{(0.0354)^2 * (1 - 0.4745) * (1.525 - 0.4745)} = 0.01919\ (\text{L.s/mol})$$

Determination of the order and the rate reaction constant using method of excess:

This method assumes one reactant as limiting and considers the other reactants are in excess. Therefore, these excess reactants will constantly affect the rate of reaction. Therefore, the whole terms related to these excess reactants' concentration are constant. Hence, the rate of reaction is the only function of the concentration of the limiting reactant with its stoichiometric power. As a result, the rate constant and stoichiometric power will be determined.

➔ $-r_A = K\, C_{NaOH}^{\alpha}$

Linearize this equation:

$\ln(-r_A) = \ln K + \alpha \ln(C_{NaOH})$

Where α is the order of the reaction

- From figure 1 :
- ✓ The slope represents the order of the reaction and it’s equal to 2.43.
- ✓ The intercept = -0.0513
- ✓ Ln(K) = -0.0513 taking the exponential from the both sides
  K = 0.949 L/mol.s

II. Date Sheet

October, 2022

Continuous Stirred Tank Reactor 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	10.8 ml
Volume of ethyl acetate sample	10 ml
Volume of NaOH added	30 ml
Volume of HCl needed for titration	12 ml

Item	Run 1	Run 2	Run 3
Flow rate of ethyl acetate	7	8	6
Flow rate of sodium hydroxide cm^3/s	7	6	8
Residence time (min)	3.2	3.2	3.2
Sample 1: Volume of NaOH (+ 20 ml HCl)	13.8	15.5	13.5
Sample 2: Volume of NaOH			
Sample 3: Volume of NaOH			
Temperature			

3/12

4