

B.M.S. COLLEGE OF ENGINEERING

Autonomous Institute, Affiliated to VTU
BENGALURU

DEPARTMENT OF CHEMICAL ENGINEERING



VI SEMESTER

CHEMICAL REACTION ENGINEERING-II

23CH6PCCR2

LABORATORY MANUAL

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**B.M.S. COLLEGE OF ENGINEERING, BENGALURU**

Autonomous Institute, Affiliated to VTU

Chemical Engineering Department

Sl no	Experiment Details	Date of the Experiment	Marks	Sign of the faculty
	PART -A EXPERIMENTS			
1.	Batch Reactor Studies for Bimolecular Saponification Reaction			
2.	Batch Reactor Studies for Second Order Saponification Reaction			
3.	Mixed Flow Reactor Studies for Second Order Saponification Reaction			
4.	RTD Studies in a Stirred Tank Reactor			
5.	Plug Flow Reactor Studies for Second Order Saponification Reaction			
6.	RTD Studies in a Tubular Flow Reactor			
7.	RTD Studies in a Packed Bed Reactor			
8.	Effect of temperature on the Kinetics of the Reaction			
9.	Semi Batch Reactor			
	PART B- Open Ended Experiments (Any One Experiment)			
10.	Comparison between Step and Pulse input during RTD Studies in a Tubular Flow Reactor			
11.	Comparison between Step and Pulse input during RTD Studies in a Packed Bed Reactor			
12.	Semi Batch Reactor experiment for different contact scheme			

LAB SAFETY GUIDELINES

1. Always behave in a responsible manner in the laboratory.
2. Always wear laboratory coat (White Color).
3. Ask your teacher before preceding any activity.
4. Keep silence in laboratory.
5. Do not touch any equipment, chemicals, or other materials in the laboratory area until you are instructed to do so.
6. Perform only those experiments authorized by your teacher.
7. Do not eat food, drink beverages, or chew gum in the laboratory. No food or drink of any kind in the laboratory.
8. Dress properly during a laboratory activity. Long hair, dangling jewellery, and loose or baggy clothing are a hazard in the laboratory. Long hair must be tied back, and all loose clothing or dangling jewellery must be secured or removed while in the laboratory.
9. Know location of all exits, evacuation route, first aid kit, eye wash, fire extinguisher, and safety shower.
10. Wear approved eye protection (safety glasses, or goggles) always in the laboratory.
11. Shoes must completely cover the foot. No sandals or crocs are allowed.
12. No equipment may be without proper training or demonstrated competency.
13. All aisles and workspace must be kept clear of clutter. Work areas should be always kept clean and tidy.
14. All exits, fire extinguishers, electrical disconnects, eye washes and safety showers must always remain accessible.
15. All equipment guards must remain in place.
16. All chemical storage rules must be always observed.
17. All chemicals must remain closed until used, and all chemicals must be marked with substance name, hazard information, concentration, date of creation, and person responsible.
18. All waste chemicals must be put in approved and labelled containers. There is to be NO hazardous waste into sinks or garbage cans.
19. Any unsafe or dangerous behaviour must be reported to the faculty.
20. Return the glassware / plastic ware after it is cleaned.
21. Wash your hands with soap after performing all experiments.
22. Obey safety rules.
23. After Completion of Experiments turn off equipment properly.
24. Drain Water and Chemicals after Compilation of Experiments.
25. Before Leaving the Laboratory turn Off Light/Fan.

EXPERIMENT NO. 1

Batch Reactor Studies for Bimolecular Saponification Reaction

AIM: Conduct experiment and determine the rate constant for the saponification reaction of NaOH (A) with ethyl acetate (B) with NaOH in a batch reactor at room temperature

THEORY: The Batch reactor operation involves mixing of reactants and the required catalyst in the reactor and allowed to react for a predetermined time till the reaction reaches equilibrium. The reactor can be operated in ideal and non-ideal modes. In an ideal batch reactor, concentration and temperature are assumed to be uniform.

The stirrer is provided in the batch reactor mainly to ensure that every element of fluid will spend same amount of time inside the reactor. From the viewpoint of thermodynamics, a batch reactor represents a closed system. The steady states of the batch reactor correspond to states of reaction equilibria.

MATERIAL BALANCE OF BATCH REACTOR

Rate of input - Rate of output - Rate of disappearance = Rate of accumulation(1)

For a batch operation, Rate of input and output are zero.

Rate of disappearance = Rate of accumulation.....(2)

Rate of disappearance (moles/Time) = $-r_A \times V$ (3)

Rate of accumulation (moles/Time) = $\frac{dN_A}{dt}$ (4)

Where, $-r_A = \text{reaction rate } \frac{\text{mol}}{\text{m}^3 \cdot \text{s}}$, $V = \text{volume of fluid } \text{m}^3$ and $N_A = \text{No. of moles reacting}$

N_A given as; $N_A = N_{A0} - N_{A0} \times X_A = N_A = N_{A0}(1 - X_A)$(5)

Substitute eq (5) and eq (3) in eq(2)

$-r_A \times V = -\frac{d[N_{A0}(1-X_A)]}{dt} = N_{A0} \times \frac{dX_A}{dt}$; Therefore $-r_A \times V = N_{A0} \times \frac{dX_A}{dt}$ on rearranging

$$t = N_{A0} \int_0^{X_A} \frac{dX_A}{-r_A \times V} = C_{A0} \int_{C_{A0}}^{C_A} \frac{dC_A}{-r_A} \quad \text{final Expression for constant volume batch reactor}$$

rate of Rxn = $-r_A = kC_A C_B$; $C_A = C_{A0}(1 - X_A)$; $C_B = C_{B0} - C_{A0}X_A$;

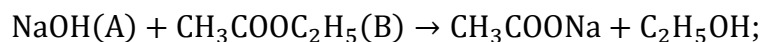
let $M = \frac{C_{B0}}{C_{A0}}$, molar ratio

$$-r_A = kC_{A0}^2(1 - X_A)(M - X_A) \dots \dots (6) \text{ Substitute this in above}$$

$$ktC_{A0} = \int_0^{X_A} \frac{dX_A}{(1-X_A)(M-X_A)} \text{ Solving the integral equation, we get}$$

$$\ln \left[\frac{M - X_A}{M(1 - X_A)} \right] = ktC_{A0}(1 - M); \text{ valid if } M \neq 1$$

Saponification reaction



Here NaOH is the limiting reactant.

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 1000ml of 0.04 N NaOH solution
- 500ml of 0.05 N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions.
3. Calculate the initial molar ratio of B to A $\left(M = \frac{C_{B0}}{C_{A0}}\right)$ from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Take 300ml of 0.04N NaOH solution in the reactor and switch on the stirrer.
5. Then add 400ml of 0.05N ethyl acetate inside the reactor and switch on the stopwatch.
6. The reaction mixture was mixed well in the reactor and 10ml of the reaction mixture is pipetted out after 2min time interval and added into the conical flask containing 0.1N HCl solution.
7. HCL will arrest the saponification reaction by neutralizing the unreacted NaOH in the pipetted-out reaction mixture.
8. The excess HCl present was estimated by titrating the against the standardized NaOH solution using phenolphthalein as indicator.
9. The step 6, 7 and 8 is repeated and collected a total of 10 samples after every 2 mins interval.

EXPERIMENTAL SET UP:

OBSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCl solution

Sl No	Volume of HCl taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl No	Time (min)	Volume of HCl added (ml)	Volume of reaction Mixture (ml)	Volume of NaOH Run down		Volume of NaOH used (V _n)
				Initial	Final	
1.	2					
2.	4					
3.	6					
4.	8					
5.	10					
6.	12					
7.	14					
8.	16					
9.	18					
10.	20					

CALCULATIONS:

Volume of Ethyl acetate taken (V_B) = 400ml; volume of NaOH taken (V_A) = 300ml

Total volume of the reactor (V_T) = $V_A + V_B$ =

Initial concentration of NaOH, $C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$

Initial concentration of Ethyl acetate, $C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$

Molar ratio, $M = \frac{C_{B0}}{C_{A0}}$

$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$

Concentration of unreacted NaOH, $C_A = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$

Where; $Z - V_n$ =

vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

$$\text{Conversion of NaOH, } X_A = 1 - \left(\frac{C_A}{C_{A0}} \right)$$

Plot graph $\ln \left[\frac{M-X_A}{M(1-X_A)} \right]$ versus t ; slope of the line is equal to $kC_{A0}(1-M)$

RESULT TABLE

Sl No	Time (min)	Concentration C_A (Moles/lit)	Conversion X_A	$\frac{M-X_A}{M(1-X_A)}$	$-\ln \left[\frac{M-X_A}{M(1-X_A)} \right]$
1.	2				
2.	4				
3.	6				
4.	8				
5.	10				
6.	12				
7.	14				
8.	16				
9.	18				
10.	20				

INFERENCE:

EXPERIMENT NO. 2

Batch Reactor Studies for Second Order Saponification Reaction

AIM: Conduct experiment and determine the rate constant for the second order saponification reaction of NaOH (A) with ethyl acetate (B) in a batch reactor.

THEORY: The Batch reactor operation involves mixing of reactants and the required catalyst in the reactor and allowed to react for a predetermined time till the reaction reaches equilibrium. The reactor can be operated in ideal and non-ideal modes. In an ideal batch reactor, concentration and temperature are assumed to be uniform.

The stirrer is provided in the batch reactor mainly to ensure that every element of fluid will spend same amount of time inside the reactor. From the viewpoint of thermodynamics, a batch reactor represents a closed system. The steady states of the batch reactor correspond to states of reaction equilibria.

MATERIAL BALANCE OF BATCH REACTOR

Rate of input - Rate of output - Rate of disappearance = Rate of accumulation(1)

For a batch operation, Rate of input and output are zero.

Rate of disappearance = Rate of accumulation.....(2)

Rate of disappearance (moles/Time) = $-r_A \times V$ (3)

Rate of accumulation (moles/Time) = $\frac{dN_A}{dt}$ (4)

Where, $-r_A$ = reaction rate $\frac{\text{mol}}{\text{m}^3 \cdot \text{s}}$, V = volume of fluid m^3 and N_A = No. of moles reacting

N_A given as; $N_A = N_{A0} - N_{A0} \times X_A = N_A = N_{A0}(1 - X_A)$(5)

Substitute eq (5) and eq (3) in eq (2)

$-r_A \times V = -\frac{d[N_{A0}(1-X_A)]}{dt} = N_{A0} \times \frac{dX_A}{dt}$; Therefore $-r_A \times V = N_{A0} \times \frac{dX_A}{dt}$ on rearranging

$$t = N_{A0} \int_0^{X_A} \frac{dX_A}{-r_A \times V} = C_{A0} \int_{C_{A0}}^{\frac{C_A}{C_{A0}}} \frac{dC_A}{-r_A} \quad \text{final Expression for constant volume batch reactor}$$

rate of Rxn = $-r_A = kC_A C_B$; $C_A = C_{A0}(1 - X_A)$; $C_B = C_{B0} - C_{A0}X_A$

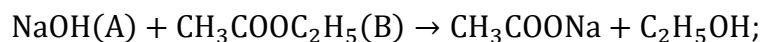
let $M = \frac{C_{B0}}{C_{A0}} = 1$, molar ratio; there fore $C_A = C_B$

$$-r_A = kC_{A0}^2(1 - X_A)^2 \dots \dots (6) \text{ Substitute this in above eq}$$

$$ktC_{A0} = \int_0^{X_A} \frac{dX_A}{(1-X_A)^2} \text{ Solving the integral equation, we get}$$

$$\frac{X_A}{(1 - X_A)} = ktC_{A0}; \text{ if } M = 1$$

Saponification reaction



Here NaOH is the limiting reactant.

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 1000ml of 0.05 N NaOH solution
- 500ml of 0.05 N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions.
3. Calculate the initial molar ratio of B to A $\left(M = \frac{C_{B0}}{C_{A0}}\right)$ from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Take 300 ml of 0.04 N NaOH solution in the reactor and switch on the stirrer.
5. Then add 300ml of 0.05 N ethyl acetate inside the reactor and switch on the stopwatch.
6. The reaction mixture was mixed well in the reactor and 10ml of the reaction mixture is pipetted out for 2min time interval and added into the conical flask containing 0.1N HCl solution.
7. HCL will arrest the saponification reaction by neutralizing the unreacted NaOH.
8. The excess HCl present was estimated by titrating the against the standardized NaOH solution using phenolphthalein as indicator.
9. The step 6, 7 and 8 is repeated and collected a total of 10 samples after every 2 mins interval.

EXPERIMENTAL SET UP:

OSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCl solution

Sl No	Volume of HCl taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl No	Time (min)	Volume of HCl added (ml)	Volume of reaction Mixture (ml)	Volume of NaOH Run down		Volume of NaOH used (V _n)
				Initial	Final	
1.	2					
2.	4					
3.	6					
4.	8					
5.	10					
6.	12					
7.	14					
8.	16					
9.	18					
10.	20					

CALCULATIONS:

Volume of Ethyl acetate taken (V_B) = 300ml; volume of NaOH taken (V_A) = 300ml

Total volume of the reactor (V_T) = $V_A + V_B$ =

Initial concentration of NaOH, $C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$

Initial concentration of Ethyl acetate, $C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$

Molar ratio, $M = \frac{C_{B0}}{C_{A0}}$

$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$

Concentration of unreacted NaOH, $C_A = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$

Where, $Z - V_n =$
vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

Conversion, $X_A = 1 - \left(\frac{C_A}{C_{A0}} \right)$

Plot graph $\frac{X_A}{(1-X_A)}$ versus t ; slope of the line is equal to kC_{A0}

RESULT TABLE

Sl No	Time (min)	Concentration C_A (Moles/lit)	Conversion X_A	$\frac{X_A}{(1 - X_A)}$
1.	2			
2.	4			
3.	6			
4.	8			
5.	10			
6.	12			
7.	14			
8.	16			
9.	18			
10.	20			

INFERENCE:

EXPERIMENT NO. 3

Mixed Flow Reactor Studies for Second Order Saponification Reaction

AIM: Conduct experiment and determine the rate constant for the second order saponification reaction of ethyl acetate (A) with NaOH (B) in a mixed flow reactor

THEORY: A mixed flow reactor also known as back mixed reactor in which the contents are well stirred and uniform throughout. Thus, the exit stream from this reactor has the same composition as the fluid within the reactor.

MATERIAL BALANCE OF MIXED FLOW REACTOR

Rate of input - Rate of output - Rate of disappearance = Rate of accumulation(1)

Rate of Input = F_{A0} (2)

Rate of output = $F_A = F_{A0}(1 - X_A)$ (3)

Rate of disappearance (moles/Time) = $-r_A \times V$ (4)

Rate of accumulation (moles/Time) = *zero*.....(5)

Where, F_{A0} = initial molar flow rate, F_A = final molar flowrate, $-r_A$ = reaction rate $\frac{\text{mol}}{\text{m}^3 \cdot \text{s}}$,

V = volume of fluid m^3 , and N_A = No. of moles reacting

$F_{A0} - F_{A0} + F_{A0} \times X_A = -r_A \times V$; $F_{A0} \times X_A = -r_A \times V$

$-r_A = \frac{F_{A0} \times X_A}{V}$; Therefore, on rearranging

$\frac{\tau}{C_{A0}} = \frac{X_A}{-r_A}$ final Expression for constant volume MFR

rate of Rxn = $-r_A = kC_A C_B$; $C_A = C_{A0}(1 - X_A)$; $C_B = C_{B0} - C_{A0}X_A$

let $M = \frac{C_{B0}}{C_{A0}} = 1$, molar ratio; there fore $C_A = C_B$

$-r_A = kC_{A0}^2(1 - X_A)^2$ (6) Substitute this in above eq

$k\tau C_{A0} = \frac{X_A}{(1 - X_A)^2}$ Solving the integral equation, we get

$$\frac{X_A}{(1-X_A)^2} = ktC_{A0} ; \text{ if } M = 1$$

Saponification reaction



Here NaOH is the limiting reactant.

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 5liters of 0.05 N NaOH solution
- 5 liters of 0.05N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions.
3. Calculate the initial molar ratio of B to A ($M = \frac{C_{B0}}{C_{A0}}$) from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Transfer 4 liters of NaOH and 4 liters of ethyl acetate into the corresponding overhead tanks.
5. The outlet taps of both overhead tanks were opened slightly and the flow rate was adjusted to about 2 lit/min for each stream and introduces both streams into the reactor. Start the stopwatch.
6. Once the flow rate reached steady state (after 10 mins), 10 ml of the existing mixture was pipette into the conical flasks containing 10ml of HCl to arrest the saponification reaction.
7. Empty the reactor and estimate the excess HCl present was determined by titrating the contents of the flask against std. NaOH solution.
8. The above procedure was repeated for 4 different flow rates viz.3, 4, 5, 6 lit/min. The observations were tabulated.

EXPERIMENTAL SET UP:

OBSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl.No	Flowrate (LPH)	Flowrate (LPH)	Time (mins)	Vol of HCl added (ml)	Vol of reaction mixture taken (ml)	Volume of NaOH in burette (ml)		Volume of NaOH rundown (ml)
	Initial	Final				Initial	Final	
1			10	10	10			
2			10	10	10			
3			10	10	10			
4			10	10	10			
5			10	10	10			

CALCULATIONS:

Initial concentration of NaOH, $C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$

Initial concentration of Ethyl acetate, $C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$

Reactor diameter = 10 cm = 0.1 m

Reactor length = 16 cm = 0.16 m

Volume of the reactor $V = \pi r^2 h = 3.14 \times (0.1/2)^2 \times 0.16 =$

Volumetric flow rate = Q

$\tau = \frac{\text{Volume of the reactor}}{\text{Volumetric flow rate}} = \text{---min}$

Molar ratio, $M = \frac{C_{B0}}{C_{A0}}$

$$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$$

$$\text{Concentration of unreacted NaOH, } C_A = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$$

Where, $Z - V_n =$

vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

$$\text{Conversion, } X_A = 1 - \left(\frac{C_A}{C_{A0}} \right)$$

Plot graph $\frac{X_A}{(1-X_A)^2}$ versus τ ; slope of the line is equal to kC_{A0}

RESULT TABLE

Sl No	Concentration C_A (Moles/lit)	Conversion X_A	Space time, τ in min	$\frac{X_A}{(1 - X_A)^2}$
1.				
2.				
3.				
4.				
5.				

INFERENCE:

EXPERIMENT NO. 4

RTD Studies in a Stirred Tank Reactor

AIM: To study the non-ideal behaviour, plot of Exit age distribution (E curve) and to calculate the mean residence time of the stirred tank reactor

THEORY: In the continuous stirred tank reactor we idealize and assume that there is perfect mixing in the reactor and that the exit concentration is same as that of the bulk fluid in CSTR. The extent of non-ideality in the reactor can be obtained by stimulus response technique. The elements of fluid taking a different route through the reactor may require different lengths of time to pass through the reactor. The distribution of these times for the stream of fluid leaving the reactor is called the Exit age distribution E, also referred to as the “Residence time distribution”.

A stirred tank reactor can be used either as batch reactor or as a flow reactor and if the flow pattern is not so different in these two arrangements, then tracer experiment in either of them will give the information needed to construct the flow model.

SOLUTIONS REQUIRED

- 2 N NaOH 100 ml
- 0.05 N Oxalic acid 100 ml
- 0.05 N HCl 500 ml

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. The overhead tank was filled with water (10 liters) and the flow rate (5lit/min or 5 lit/hr) was adjusted for steady state condition. The flow rate of water was noted down.
3. Make sure the reactor is filled with water and starts to overflow at a constant flow rate, later add 10 ml of NaOH solution into the reactor at once using a syringe. Simultaneously the stopwatch and stirrer were started.
4. 10 ml of the overflow was collected into the conical flasks at the end of every 30 seconds interval, for a period of ten minutes.
5. This was titrated against 0.1 HCl solutions taken in a burette.
6. Readings were tabulated and the ‘Residence time Distribution’ was calculated.
7. The following graphs were plotted for E vs t ; C_i vs t and $C_i t$ vs t

EXPERIMENTAL SET UP:

OBSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl.No	Time, sec	Volume of HCl (ml)		Volume of HCl rundown (ml)
		Initial	Final	
1.	0			
2.	30			
3.	60			
4.	90			
5.	120			
6.	150			
7.	180			
8.	210			
9.	240			
10.	270			
11.	300			
12.	360			
13.	420			
14.	480			
15.	540			

CALCULATIONS:

Initial concentration of NaOH, $C_{A0} = \text{Normality of NaOH}$

$C_i = (\text{NV})_{\text{HCl}} / \text{Volume of reaction mixture}$

$C_i \times \Delta t =$; Area under the C-curve by analytical method $= \sum_{i=0}^n C_i \times \Delta t = \frac{M}{v}, \frac{\text{kg.s}}{\text{m}^3}$

where; v = volumetric flow rate of water, $\frac{m^3}{s}$ and M = moles or kg of tracer used

$$E = RTD = \frac{C_i}{\left(\frac{M}{v}\right)}; \text{ Mean residence time, } t_{\text{analytical}} = \frac{\sum t.C_i.\Delta t}{\sum C_i \Delta t}; \text{ Mean residence time, } t_{\text{graphical}} = \frac{\int t.C_i.dt}{\int C_i dt}$$

RESULT TABLE

Sl.No	Time (sec)	Titre value (ml)	Tracer concentration C_i (g mol/ lit)	$C_i \Delta t$ (g mol sec/ lit)	$E = \frac{C_i}{\left(\frac{M}{v}\right)}$	$t. C_i. \Delta t$ (g mol sec ² / lit)
1.	0					
2.	30					
3.	60					
4.	90					
5.	120					
6.	150					
7.	180					
8.	210					
9.	240					
10.	270					
11.	300					
12.	360					
13.	420					
14.	480					
15.	540					
$\sum C_i \Delta t = Q =$					$\sum t. C_i. \Delta t$	

INFERENCE:

EXPERIMENT NO. 5

Plug Flow Reactor Studies for Second Order Saponification Reaction

AIM: Conduct experiment and determine the rate constant for the second order saponification reaction of ethyl acetate (A) with NaOH (B) in a plug flow reactor

THEORY: The plug flow reactor model (PFR, sometimes called continuous tubular reactor, CTR, or piston flow reactors) is a model used to describe chemical reactions in continuous, flowing systems of cylindrical geometry. The PFR model is used to predict the behavior of chemical reactors of such design, so that key reactor variables, such as the dimensions of the reactor, can be estimated.

MATERIAL BALANCE OF PLUG FLOW REACTOR

Rate of input - Rate of output - Rate of disappearance = Rate of accumulation(1)

Rate of Input = F_A (2)

Rate of output = $F_A + dF_A$ (3)

Rate of disappearance (moles/Time) = $-r_A \times dV$ (4)

Rate of accumulation (moles/Time) = *zero*.....(5)

$F_A - F_A - dF_A = -r_A \times dV$; $F_{A0} \times dX_A = -r_A \times dV$

$-r_A = \frac{F_{A0} \times dX_A}{dV}$; Therefore, on rearranging

$\frac{\tau}{C_{A0}} = \frac{V}{F_{A0}} = \int_0^{X_A} \frac{dX_A}{-r_A}$ *final Expression for constant volume MFR*

rate of Rxn = $-r_A = kC_A C_B$; $C_A = C_{A0}(1 - X_A)$; $C_B = C_{B0} - C_{A0}X_A$

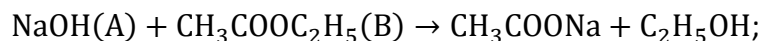
let $M = \frac{C_{B0}}{C_{A0}} = 1$, molar ratio ; there fore $C_A = C_B$

$-r_A = kC_{A0}^2(1 - X_A)^2$ (6) Substitute this in above eq

$k\tau C_{A0} = \frac{X_A}{1-X_A}$ Solving the integral equation, we get

$\frac{X_A}{1-X_A} = ktC_{A0} ; \text{ if } M = 1$
--

Saponification reaction



Here NaOH is the limiting reactant.

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 5liters of 0.05 N NaOH solution
- 5 liters of 0.05N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions.
3. Calculate the initial molar ratio of B to A $\left(M = \frac{C_{B0}}{C_{A0}}\right)$ from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Transfer 4 liters of NaOH and 4 liters of ethyl acetate into the corresponding overhead tanks.
5. The outlet taps of both overhead tanks were opened slightly and the flow rate was adjusted to about 2 lit/min for each stream and introduces both streams into the reactor. Start the stopwatch.
6. Once the flow rate reached steady state (after 10 mins), 10 ml of the existing mixture was pipette into the conical flasks containing 10ml of HCl to arrest the saponification reaction.
7. Empty the reactor and estimate the excess HCl present was determined by titrating the contents of the flask against std. NaOH solution.
8. The above procedure was repeated for 4 different flow rates viz.3, 4, 5, 6 lit/min. The observations were tabulated.

EXPERIMENTAL SET UP:

OBSERVATIONS

4. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

5. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

6. Observation Table

Sl.No	Flowrate (LPH)	Flowrate (LPH)	Time (mins)	Vol of HCl added (ml)	Vol of reaction mixture taken (ml)	Volume of NaOH in burette (ml)		Volume of NaOH rundown (ml)
	Initial	Final				Initial	Final	
1			10	10	10			
2			10	10	10			
3			10	10	10			
4			10	10	10			
5			10	10	10			

CALCULATIONS:

$$\text{Initial concentration of NaOH, } C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$$

$$\text{Initial concentration of Ethyl acetate, } C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$$

$$\text{Reactor diameter} = 10 \text{ cm} = 0.1 \text{ m}$$

$$\text{Reactor length} = 2.0 \text{ m}$$

$$\text{Volume of the reactor } V = \pi r^2 L =$$

$$\text{Volumetric flow rate} = Q$$

$$\tau = \frac{\text{Volume of the reactor}}{\text{Volumetric flow rate}} = \text{---} \text{---} \text{---} \text{---} \text{---} \text{min}$$

$$\text{Molar ratio, } M = \frac{C_{B0}}{C_{A0}}$$

$$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$$

Concentration of unreacted NaOH, $C_A = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$

Where, $Z - V_n =$

vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

Conversion, $X_A = 1 - \left(\frac{C_A}{C_{A0}} \right)$

Plot graph $\frac{X_A}{1 - X_A}$ versus τ ; slope of the line is equal to kC_{A0}

RESULT TABLE

Sl No	Concentration C_A (Moles/lit)	Conversion X_A	Space time, τ in min	$\frac{X_A}{1 - X_A}$
1.				
2.				
3.				
4.				
5.				

INFERENCE:

EXPERIMENT NO. 6

RTD Studies in a Tubular Flow Reactor

AIM: To study the non-ideal behaviour, plot of Exit age distribution (E curve) and to calculate the mean residence time of the tubular reactor

THEORY: In the continuous stirred tank reactor we idealize and assume that there is perfect mixing in the reactor and that the exit concentration is same as that of the bulk fluid in CSTR.

The extent of non-ideality in the reactor can be obtained by stimulus response technique. The elements of fluid taking a different route through the reactor may require different lengths of time to pass through the reactor. The distribution of these times for the stream of fluid leaving the reactor is called the Exit age distribution E, also referred to as the “Residence time distribution”.

A stirred tank reactor can be used either as batch reactor or as a flow reactor and if the flow pattern is not so different in these two arrangements, then tracer experiment in either of them will give the information needed to construct the flow model.

SOLUTIONS REQUIRED

- 2 N NaOH 100 ml
- 0.05 N Oxalic acid 100 ml
- 0.05 N HCl 500 ml

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. The overhead tank was filled with water (10 liters) and the flow rate (5lit/min or 5 lit/hr) was adjusted for steady state condition. The flow rate of water was noted down.
3. Make sure the reactor is filled with water and starts to overflow at a constant flow rate, later add 10 ml of NaOH solution into the reactor at once using a syringe. Simultaneously the stopwatch and stirrer were started.
4. 10 ml of the overflow was collected into the conical flasks at the end of every 30 seconds interval, for a period of ten minutes.
5. This was titrated against 0.1 HCl solutions taken in a burette.
6. Readings were tabulated and the ‘Residence time Distribution’ was calculated.
7. The following graphs were plotted for E vs t ; C_i vs t and $C_i t$ vs t

EXPERIMENTAL SET UP:

OBSERVATIONS

7. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

8. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

9. Observation Table

Sl.No	Time, sec	Volume of HCl (ml)		Volume of HCl rundown (ml)
		Initial	Final	
1.	0			
2.	30			
3.	60			
4.	90			
5.	120			
6.	150			
7.	180			
8.	210			
9.	240			
10.	270			
11.	300			
12.	360			
13.	420			
14.	480			
15.	540			

CALCULATIONS:

Initial concentration of NaOH, C_{A0} = Normality of NaOH

C_i = (NV)_{HCl} / Volume of reaction mixture

$C_i \times \Delta t =$; Area under the C-curve by analytical method = $\sum_{i=0}^n C_i \times \Delta t = \frac{M}{v}$, $\frac{kg.s}{m^3}$

where; v = volumetric flow rate of water, $\frac{m^3}{s}$ and M = moles or kg of tracer used

$$E = RTD = \frac{C_i}{\left(\frac{M}{v}\right)}; \text{ Mean residence time, } t_{\text{analytical}} = \frac{\sum t.C_i.\Delta t}{\sum C_i \Delta t}; \text{ Mean residence time, } t_{\text{graphical}} =$$

$$\frac{\int t.C_i.d t}{\int C_i d t}$$

RESULT TABLE

Sl.No	Time (sec)	Titre value (ml)	Tracer concentration C_i (g mol/ lit)	$C_i \Delta t$ (g mol sec/ lit)	$E = \frac{C_i}{\left(\frac{M}{v}\right)}$	$t. C_i. \Delta t$ (g mol sec ² / lit)
1.	0					
2.	30					
3.	60					
4.	90					
5.	120					
6.	150					
7.	180					
8.	210					
9.	240					
10.	270					
11.	300					
12.	360					
13.	420					
14.	480					
15.	540					
$\sum C_i \Delta t = Q =$					$\sum t. C_i. \Delta t$	

INFERENCE:

EXPERIMENT NO. 7

RTD Studies in a Packed Bed Reactor

AIM: To study the non-ideal behaviour, plot of Exit age distribution (E curve), F curve and to calculate the mean residence time of the packed bed reactor.

THEORY:

A typical packed bed is a cylindrical column that is filled with a suitable packing material. The liquid is distributed as uniformly as possible at the top of the column and flows downward, wetting the packing material. An example of a packed bed is an absorber set up. Few fluids mechanical issues in packed bed involve proper distribution of the liquid across the cross-section, which can be studied by using RTD studies.

A gas is admitted at the bottom, and flows upward, contacting the liquid in a counter current fashion.

The extent of non-ideality in the reactor can be obtained by step response technique. The concentration of tracer in a step experiment at the reactor inlet changes abruptly from 0 to C_0 . The concentration of tracer at the outlet is measured and normalized to the concentration C_0 to obtain the non-dimensional curve $F(t)$ which goes from 0 to 1.

$$F(t) = \int_0^t E(t) dt$$

$F(t)$ is called “cumulative distribution

An ideal plug flow reactor has a fixed residence time. The residence time distribution function is therefore a dirac delta function.

SOLUTIONS REQUIRED

- 0.1 N NaOH 5 liters
- 0.05 N Oxalic acid 100 ml
- 0.05 N HCl 500 ml

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. The overhead tank was filled with water (5 liters) and NaOH solution in the other tank.
3. The flow rate of the water was adjusted for steady state condition using rotameter (5 lit/hr or 5 lit/min). The flow rate of water was noted down.
4. Once the water flows out of the packed bed reactor, the water flow rate was stopped, and (5 lit/hr or 5 lit/min) of NaOH was allowed to flow into the reactor. As soon as the NaOH was added into the reactor, simultaneously the stopwatch.

- 10 ml of the reaction mixture flowing out of the reactor was collected into the conical flasks at the end of every 30 seconds interval, for a period of ten minutes.
- This was titrated against 0.1 HCl solutions taken in a burette.
- Readings were tabulated and the E and F curve was calculated.
- The following graphs were plotted for E vs t: F vs. t ; C_i vs t and $C_i t$ vs t

EXPERIMENTAL SET UP:

OBSERVATIONS

- Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

- Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl.No	Time, sec	Volume of HCl (mL)		Volume of HCl rundown (mL)
		Initial	Final	
1.	0			
2.	30			
3.	60			
4.	90			
5.	120			
6.	150			
7.	180			
8.	210			
9.	240			
10.	270			
11.	300			
12.	360			
13.	420			
14.	480			
15.	540			

CALCULATIONS:

Initial concentration of NaOH, C_{A0} = Normality of NaOH

C_i = (NV)_{HCl} / Volume of reaction mixture

$C_i \times \Delta t$ = ; Area under the C-curve by analytical method = $\sum_{i=0}^n C_i \times \Delta t = \frac{M}{v}$, $\frac{kg.s}{m^3}$

where; v = volumetric flow rate of water, $\frac{m^3}{s}$ and M = moles or kg of tracer used

$$F = RTD = \frac{v}{M} C_{step}$$

$$F = \frac{C_{out}}{C_o}, \quad E = \frac{dF}{dt} = RTD$$

$$\text{Mean residence time, } t_{\text{analytical}} = \frac{\sum t_i C_i \Delta t}{\sum C_i \Delta t} ; \quad \text{Mean residence time, } t_{\text{graphical}} = \frac{\int t_i C_i dt}{\int C_i dt}$$

RESULT TABLE

Sl.No	Time (sec)	Titre value (ml)	Tracer concentration C_i (g mol/ lit)	$C_i \Delta t$ (g mol sec/ lit)	$F = \frac{C_{out}}{C_o}$	$E = \frac{\Delta F}{\Delta t}$	$t_i C_i \Delta t$ (g mol sec ² / lit)
1.	0						
2.	30						
3.	60						
4.	90						
5.	120						
6.	150						
7.	180						
8.	210						
9.	240						
10.	270						
11.	300						
12.	360						
13.	420						
14.	480						
15.	540						
$\sum C_i \Delta t = Q =$					$\sum t_i C_i \Delta t$		

INFERENCE:

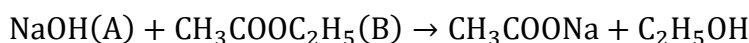
EXPERIMENT NO. 8

Semi Batch Reactor

AIM: Conduct experiment and determine the rate constant for the second order saponification reaction of NaOH (A) with ethyl acetate (B) in a plug flow reactor

THEORY: The plug flow reactor model (PFR, sometimes called continuous tubular reactor, CTR, or piston flow reactors) is a model used to describe chemical reactions in continuous, flowing systems of cylindrical geometry. The PFR model is used to predict the behavior of chemical reactors of such design, so that key reactor variables, such as the dimensions of the reactor, can be estimated

Saponification reaction



Here NaOH is the limiting reactant

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 5liters of 0.04N NaOH solution
- 1000 ml of 0.05N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions
3. Calculate the initial molar ratio of B to A ($M = \frac{C_{B0}}{C_{A0}}$) from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Transfer 4 liters of NaOH into the overhead tank and transfer 500 ml ethyl acetate into the reactor.
5. The outlet tap of the overhead tanks were opened slightly and the flow rate was adjusted to about 5.0 lit/min and allowed into the reactor. Start the stop watch.
6. The reaction mixture was mixed well in the reactor and 10ml of the reaction mixture is pipetted out for 2min time interval and added into the conical flask containing 0.1N HCl solution to arrest the saponification reaction by neutralizing the unreacted NaOH.
7. The excess HCl present was estimated by titrating the against the standardized NaOH solution using phenolphthalein as indicator.
8. Repeat the experiment for different flow rate around 10 lit/min.

EXPERIMENTAL SET UP:

OBSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl.No	Flowrate (LPH)	Time (mins)	Vol of HCl added (ml)	Vol of reaction mixture taken (ml)	Volume of NaOH in burette (ml)		Volume of NaOH rundown (ml)
	Initial				Initial	Final	
1		2	10	10			
2		4	10	10			
3		6	10	10			
4		8	10	10			
5		10	10	10			
6		12	10	10			
7		14	10	10			
8		16	10	10			
9		18	10	10			
10		20	10	10			

CALCULATIONS:

Volume of Ethyl acetate taken (V_B) = 500ml;

volume of NaOH taken (V_A) =

Total volume of the reactor (V_T) = $V_A + V_B$ =

Initial concentration of Ethyl acetate, $C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$

Initial concentration of NaOH, $C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$

$\tau = \frac{\text{Volume of the reactor}}{\text{Volumetric flow rate}} = \text{---min}$

$$\text{Molar ratio, } M = \frac{C_{B0}}{C_{A0}}$$

$$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$$

$$\text{Volume of the reactor } V = \pi r^2 h =$$

$$\text{Concentration of unreacted NaOH, } C_B = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$$

$$\text{Where, } Z - V_n =$$

vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

$$\text{Conversion of ethyl acetate, } X_A = 1 - \left(\frac{C_A}{C_{A0}} \right)$$

$$C_{A_{theo}} = \frac{C_{A0}}{\tau \left(k + \frac{1}{\tau} \right)} + \left[C_{A0} - \frac{C_{A0}}{\tau \left(k + \frac{1}{\tau} \right)} \right] \times \exp \left[- \left(k + \frac{1}{\tau} \right) \right]$$

$$X_{A_{theo}} = 1 - \frac{C_{A_{theo}}}{C_{A0}}$$

RESULT TABLE

Sl No	Time (min)	Concentration C_A (Moles/lit)	Conversion X_A	$C_{A_{theo}}$	$X_{A_{theo}}$
1.	2				
2.	4				
3.	6				
4.	8				
5.	10				
6.	12				
7.	14				
8.	16				
9.	18				
10.	20				

INFERENCE:

EXPERIMENT NO. 9

Effect of Temperature on the Kinetics of the Reaction

Aim: To estimate the effect of temperature on the rate constant (k) for the saponification of ethyl acetate by sodium hydroxide (NaOH) in a Batch Reactor

Apparatus required: Glass beaker 2 liter, Magnetic stirrer with hot plate, burette, pipette, 8 conical flasks and stopwatch

Theory: The Batch reactor operation involves mixing of reactants and the required catalyst in the reactor and allowed to react for a predetermined time till the reaction reaches equilibrium. The reactor can be operated in ideal and non-ideal modes. In an ideal batch reactor, concentration and temperature are assumed to be uniform inside the reactor.

MATERIAL BALANCE OF BATCH REACTOR

Rate of input - Rate of output - Rate of disappearance = Rate of accumulation(1)

For a batch operation, Rate of input and output are zero.

Rate of disappearance = Rate of accumulation.....(2)

Rate of disappearance (moles/Time) = $-r_A \times V$ (3)

Rate of accumulation (moles/Time) = $\frac{dN_A}{dt}$ (4)

Where, $-r_A$ = reaction rate $\frac{\text{mol}}{\text{m}^3 \cdot \text{s}}$, V = volume of fluid m^3 and N_A = No. of moles reacting

N_A given as; $N_A = N_{A0} - N_{A0} \times X_A = N_A = N_{A0}(1 - X_A)$(5)

Substitute eq (5) and eq(3) in eq(2)

$-r_A \times V = -\frac{d[N_{A0}(1-X_A)]}{dt} = N_{A0} \times \frac{dX_A}{dt}$; Therefore $-r_A \times V = N_{A0} \times \frac{dX_A}{dt}$ on rearranging

$t = N_{A0} \int_0^{X_A} \frac{dX_A}{-r_A \times V} = C_{A0} \int_{C_{A0}}^{C_A} \frac{dC_A}{-r_A}$	<i>final Expresion for constant volume batch reactor</i>
---	--

rate of Rxn = $-r_A = kC_A C_B$; $C_A = C_{A0}(1 - X_A)$; $C_B = C_{B0} - C_{A0}X_A$;

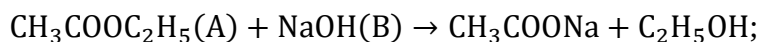
let $M = \frac{C_{B0}}{C_{A0}}$, molar ratio

$$-r_A = kC_{A0}^2(1 - X_A)(M - X_A) \dots \dots (6) \text{ Substitute this in eqabove}$$

$$ktC_{A0} = \int_0^{X_A} \frac{dX_A}{(1-X_A)(M-X_A)} \text{ Solving the integral equation, we get}$$

$$\ln \left[\frac{M - X_A}{M(1 - X_A)} \right] = ktC_{A0}(1 - M); \text{ valid if } M \neq 1$$

Saponification reaction



Here NaOH is the limiting reactant.

SOLUTIONS REQUIRED

- 100 ml of 0.1N oxalic acid solution
- 1000ml of 0.04N NaOH solution
- 500ml of 0.05N ethyl acetate solution
- 500ml of 0.1N HCl solution

PROCEDURE:

1. Standardize the NaOH stock solution using oxalic acid solution and note down its Normality.
2. Calculate the initial concentration of ethyl acetate and NaOH solutions.
3. Calculate the initial molar ratio of B to A $\left(M = \frac{C_{B0}}{C_{A0}}\right)$ from stock concentration of ethyl acetate and the stock concentration of NaOH.
4. Take 300 ml of 0.04N NaOH solution in the reactor and switch on the stirrer.
5. Then add 400ml of 0.05N ethyl acetate inside the reactor and switch on the stopwatch.
6. Maintain the temperature of the reaction mixture above room temperature and note down the temperature.
7. The reaction mixture was mixed well in the reactor and 10ml of the reaction mixture is pipetted out for 2 min time interval and added into the conical flask containing 0.1N HCl solution to arrest the saponification reaction by neutralizing the unreacted NaOH.
8. The excess HCl present was estimated by titrating the against the standardized NaOH solution using phenolphthalein as indicator.
9. Repeat the same steps for different temperature.

EXPERIMENTAL SET UP:

OBSERVATIONS

1. Standardization of NaOH solution

Sl No	Volume of NaOH taken	Volume of Oxalic acid Run down	
		Initial	Final

2. Standardization of HCL solution

Sl No	Volume of HCL taken	Volume of NaOH Run down	
		Initial	Final

3. Observation Table

Sl No	Time (min)	Volume of HCl added (ml)	Volume of reaction Mixture (ml)	Volume of NaOH Run down		Volume of NaOH used (V _n)
				Initial	Final	
1.	2					
2.	4					
3.	6					
4.	8					
5.	10					
6.	12					
7.	14					
8.	16					
9.	18					
10.	20					

CALCULATIONS:

Volume of Ethyl acetate taken (V_B) = 400ml; volume of NaOH taken (V_A) = 300ml

Total volume of the reactor (V_T) = $V_A + V_B$ =

Initial concentration of NaOH, $C_{A0} = \frac{\text{Normality of NaOH} \times V_A}{V_T}$

Initial concentration of Ethyl acetate, $C_{B0} = \frac{\text{Normality of EA} \times V_B}{V_T}$

Molar ratio, $M = \frac{C_{B0}}{C_{A0}}$

$Z = \frac{(V \times N)_{\text{HCl}}}{N_{\text{NaOH}}} = \text{volume of NaOH used to neutralize 10ml HCl completely}$

Concentration of unreacted NaOH, $C_A = \frac{N_{\text{NaOH}} \times (Z - V_n)}{\text{volume of reaction mixture}}$

Where, $Z - V_n =$

vol. of HCl required to neutralize which proportional to vol. of NaOH reacted

Conversion of ethyl acetate, $X_A = 1 - \left(\frac{C_A}{C_{A0}}\right)$

Plot graph $\ln \left[\frac{M-X_A}{M(1-X_A)} \right]$ versus t; slope of the line is equal to $kC_{A0}(1-M)$

Slope = $kC_{A0}(1-M)$; $k = \text{Slope}/C_{A0}(1-M)$

k has units of L/gmol min

Effect of temperature on rate constant $\ln \left(\frac{k_1}{k_2} \right) = -\frac{E}{R} \left[\frac{1}{T_2} - \frac{1}{T_1} \right]$ find the Activation Energy E.

Units of E is J/gmol.

RESULT TABLE

Sl No	Time (min)	Concentration C_A (Moles/lit)	Conversion X_A	$\frac{M-X_A}{M(1-X_A)}$	$-\ln \left[\frac{M-X_A}{M(1-X_A)} \right]$
1.	2				
2.	4				
3.	6				
4.	8				
5.	10				
6.	12				
7.	14				
8.	16				
9.	18				
10.	20				

INFERENCE: