**Laboratory Manual for**

**3170501 –**

**Chemical Reaction Engineering II**



 **LUKHDHIRJI ENGINEERING COLLEGE, MORBI**

**VISION**

To provide quality engineering education and transforming students into professionally competent and socially responsible human beings.

**MISSION**

1. To provide a platform for basic and advanced engineering knowledge to meet global challenges.
2. To impart state-of-art know- how with managerial and technical skills.
3. To create a sustainable society through ethical and accountable engineering practices.

**LUKHDHIRJI ENGINEERING COLLEGE, MORBI**

 **CHEMICAL ENGINEERING DEPARTMENT**

**VISION**

To develop professionally competent & socially responsible chemical engineers by providing quality education.

**MISSION**

1. To provide sound basic engineering knowledge to have a successful career in a professional environment.
2. To develop skill sets among the students to make them professionally competent.
3. To cater ethically strong engineers who shall be able to improve the quality of life and to work for sustainable development of society.

PEO’s

PEO-1 To impart knowledge and skills in students to make them professionally competent in chemical process industries.

PEO-2 To motivate students for higher studies in technical and management fields.

PEO-3 To prepare students having soft skills along with leadership quality and management ability to make them successful entrepreneurs.

PEO-4 To implant the ethical principle and norms of engineering practices in terms of health, safety, and environmental context for the sustainable development of society.

**PROGRAM OUTCOMES (POs)**

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

**PSO**

1) Apply the knowledge of chemical engineering to accomplish the contemporary need of chemical & Allied Industries.

2) To execute the chemical engineering principle and modern engineering tools to design system by considering safety, cost, health, legal, cultural and environmental aspects.

**Chemical Engineering Department**

**Laboratory Safety Rules**

1 Behave in a responsible manner at all times in the laboratory.

2 Ask your teacher before preceding any activity.

3 Keep silence.

4 Do not touch any equipment, chemicals, or other materials in the laboratory area until you are instructed to do so.

5 Perform only those experiments authorized by your teacher.

6 Do not eat food, drink beverages, or chew gum in the laboratory.

7 Always work in a well-ventilated area.

8 Work areas should be kept clean and tidy at all times.

9 Wash your hands after performing all experiments.

10 Dress properly during a laboratory activity. Long hair, dangling jewellery, and loose or baggy clothing are a hazard in the laboratory.

11 Never look into a container that is being heated.

12 Obey safety rules.

13 After Completion of Experiments turn off equipment properly.

14 Drain Water After Compilation of Experiments.

15 Before Living the Laboratory turns Off Light/Fan.

**Undertaking of Ethics**

1. I, hereby, promise to abide by the admissible rules and regulations, concerning discipline, attendance, etc. of the L.E.C.MORBI, and also to follow the Code of Conduct prescribed for the Students of the Institute, as in force from time to time and subsequent changes/modifications/amendment made thereto. I acknowledge that, the Institute has the authority for taking punitive actions against me for violation and/or non-compliance of the same.
2. I have performed all the experiments and their calculation done myself.

**Signature of Student**

**Enrolment of Student**

**List of Equipments:**

|  |  |
| --- | --- |
| Sr. No. | Name of Instrument/Equipment in CRE Lab |
| 1 | Plug Flow Reactor Straight Tube Type |
| 2 | Cascade in CSTR  |
| 3 | Packed Bed Reactr |
| 4 | Batch Reactor |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sr. No.** | **Experiment No./Assignment No./Project work** | **Title of Experiment/Project** | **Date of Submission** | **Teacher’s sign** | **Remarks/Marks Obtained** |
| 1 | Experiment 1 | To prepare Ni / γ-Al2O3 supported catalyst by wet impregnation Method. |  |  |  |
| 2 | Experiment 2 | Characterize heterogeneous catalyst (Catalyst Characterization) –Theoretical studies: Find surface area, porosity, density, nature (acidic/basic) of catalyst and strength of active site (strong acidic/basic, weak acidic/basic), dispersion of active metal, thermal stability of catalyst, composition of catalyst, surface morphology, pore diameter, crystalline or Amorphus nature and crystal size determination. |  |  |  |
| 3 | Experiment 3 | Experiment on determining the mass transfer zone and an absorber’s mass balance and efficiency .....Studies of counter-current flow pattern in packed bed using CO2 absorption with chemical reaction with NaOH solution.  |  |  |  |
| 4 | Experiment 4 | Studies of flow pattern (co-current) in bubble column using CO2 absorption with chemical reaction with NaOH solution.  |  |  |  |
| 5 | Experiment 5 | Studies of solid fluid reaction (non catalytic) using CaCO3 with HCl solution and verify SCM. |  |  |  |
| 6 | Experiment 6 | Develop LHHW model based mechanism, a rate-limiting step, and a rate law consistent with experimental observation for catalytic reaction of the decomposition of cumene to form benzene and propylene. Theoretical Studies only) |  |  |  |
| 7 | Experiment 7 | To carry out catalytic reaction for wastewater treatment and measure extent of degradation. |  |  |  |
| 8 | Experiment 8 | To find effectiveness factor and effect of diffusion resistance in solid catalyst. |  |  |  |
| 9 | Experiment 9 | To observe fluidization behaviour in fluidized bed reactor (Demonstration experiment) |  |  |  |
| 10 | Experiment 10 | Simulation using DWSIM for any heterogeneous catalytic reaction with available kinetic data |  |  |  |
|  |  | Experiment on the Adsorption of oxalic acid (or any other suitable organic compound) on activated Carbon. |  |  |  |

|  |  |
| --- | --- |
|  | LUKHDHIRJI ENGINEERING COLLEGE, MORBI-2CHEMICAL ENGINEERING DEPARTMENTLABORATORY MANUALCHEMICAL REACTION ENGINEERING - 2 (3170501) DIVISION - 7 List of Experiments |
| **Sr. No.** | **Experiment No./Assignment No./Project work** | **Experiment Name** | **Experiment Setup used** | **Mapping with CO** | **Mapping of PO and PSOs** | **Tentative Scheduled Week for Performance** |
| 1 | Experiment 1 | To prepare Ni / γ-Al2O3 supported catalyst by wet impregnation Method. | Batch reactor | 3170501.1 | PO1, 2, 3, 8, 9, 12, PSO1,  | 1st week |
| 2 | Experiment 2 | Characterize heterogeneous catalyst (Catalyst Characterization) –Theoretical studies: Find surface area, porosity, density, nature (acidic/basic) of catalyst and strength of active site (strong acidic/basic, weak acidic/basic), dispersion of active metal, thermal stability of catalyst, composition of catalyst, surface morphology, pore diameter, crystalline or Amorphus nature and crystal size determination. | Not required | 3170501.1 | PO1, 2, 8, 9, 12, PSO1 | 2nd week |
| 3 | Experiment 3 | Studies of counter-current flow pattern in packed bed using CO2 absorption with chemical reaction with NaOH solution.  | Packed bed column | 3170501.2 | PO1, 2, 8, 9, 12, PSO1 | 3rd week |
| 4 | Experiment 4 | Studies of flow pattern (co-current) in bubble column using CO2 absorption with chemical reaction with NaOH solution.  | Packed bed column | 3170501.2 | PO1, 2, 8, 9, 12, PSO1 | 4th Week |
| 5 | Experiment 5 | Studies of solid fluid reaction (non catalytic) using CaCO3 with HCl solution and verify SCM. | Batch reactor | 3170501.3 | PO1, 2, 8, 9, 12, PSO1 | 5th Week |
| 6 | Experiment 6 | Develop LHHW model based mechanism, a rate-limiting step, and a rate law consistent with experimental observation for catalytic reaction of the decomposition of cumene to form benzene and propylene. Theoretical Studies only) | Not required | 3170501.3 | PO1, 2, 8, 9, 12, PSO1 | 6th Week |
| 7 | Experiment 7 | To carry out catalytic reaction for wastewater treatment and measure extent of degradation. | Batch reactor | 3170501.4 | PO1, 2, 8, 9, 12, PSO1 | 7th Week |
| 8 | Experiment 8 | To find effectiveness factor and effect of diffusion resistance in solid catalyst. | Batch reactor | 3170501.4 | PO1, 2, 8, 9, 12, PSO1 | 8th week |
| 9 | Experiment 9 | To observe fluidization behaviour in fluidized bed reactor (Demonstration experiment) | Fluidized bed setup | 3170501.4 | PO1, 2, 8, 9, 12, PSO1 | 10th week |
| 10 | Experiment 10 | Simulation using DWSIM for any heterogeneous catalytic reaction with available kinetic data | Computer system | 3170501.4 | PO1, 2, 8, 9, 12, PSO1 | 11th week |
|  |  |

Experiment No:

Experiment No: Date:

**SYNTHESIS OF SOLID CATALYST**

**Objective:** To synthesize catalysts for wastewater treatment. (CO-1)

**Apparatus:** Glass beaker, flask, burette, pipette, magnetic stirrer,

**Chemicals:** Distilled water, Zinc nitrate (hydrated or anyhydrous..any one) powder, TiO2 powder

**Theory:** List various generalize components of commercial catalyst and discuss its significance in catalyst performance. List various catalyst preparation methods and its applications.

**Procedure:** 10% (w/w) Zinc oxide (ZnO) loaded on titanium dioxide (TiO2) is to be prepared. Follow the procedure given below.

* Take 10 g TiO2 and add 10 ml distilled water were mixed to produce a slurry.
* Prepare 10 gram catalyst having 5%, 10%, 15% and 20% (wt. basis) of zinc oxide on titanium dioxide. (Consider group 1 will prepare 5% ZnO on TiO2, Group 2, 3 and 4 respetively 10%, 15% and 20% ZnO on TiO2).
* Calculate amount of Zinc nitrate required (read molecular weight given on box).
* Take required quantity of zinc nitrate and dissolve in 10 ml of water.
* Add zinc solution to the slurry of TiO2 and continue stirring for 60 min. at room temperature.
* Allow solution to settle down and decante excess water from mixture.
* Remove remaining moisture from the mixture in oven at 120 0C.
* Crush solid lumps and make fine powder.
* Carry out calcination at 400 °C for 6 h.
* Measure weight of final x% ZnO loaded on TiO2 photocatalyst.
* Store fine powder in a suitable air tight sampler and keep it in a desiccator.

**Results:**

Wt. of solid ZnO on TiO2 catalyst =

**Conclusion:**

**Quiz:**

1. List various catalyst synthesis methods and describe in brief.
2. Discuss various methods to synthesize nano-catalysts.
3. List various reactions and catalysts used for such reactions. Also mention reaction conditions for such reactions.

 Date:

 **To prepare Ni / γ-Al2O3 supported catalyst by wet impregnation Method**

**Objective:** To prepare Ni / γ-Al2O3 supported catalyst by wet impregnation Method (CO-1)

**Chemicals Used:** Nickel Nitrate (Ni(NO3)2.6H2O), Aluminium Oxide (Al2O3), Distilled Water (H2O)

**Apparatus and Equipment Used:** Glass Beaker (50 ml), Digital Weighing Balance, Measuring Cylinder, Shaking Bath, Oil Bath, Hot Air Oven, Muffle Furnace

**Theory:** A catalyst can be defined as a substance, a small amount that alters (increases or decreases) the rate of a chemical reaction without itself undergoing any change in mass and composition at the end of reaction. A catalyst can be synthetic, organic or simply a metal.

Catalyst mainly divided in two parts based on their method of preparation.

1. **Bulk Catalyst**
* Precipitation
* Sol-Gel Method
* Citrate Method
1. **Supported Catalyst**
* Impregnation
* Ion Exchange
* Adsorption
* Desorption

Preparation of supported catalyst is Deposition of a precursor of the active phase onto the surface of the support. Most catalysts need to be supported to avoid Sintering. The support carries the active components, provides surface area (porosity) and keeps high dispersion of active component, thermally stable and chemically inert.

The common supports used for catalyst preparation are Alumina (mostly ϒ-phase, SA up to 400 m2g-1), Silica (amorphous, SA up to 1000 m2g-1), Carbon (amorphous, SA up to 1000 m2g-1), Zeolites, TiO2, MgO.

**Procedure:**

Impregnation method is of two type Dry Impregnation and Wet impregnation.

These are main steps of wet impregnation method.

* Mixing of Precursor solution and porous Oxide (Support)
* Shaking
* Evaporation
* Drying in Hot air oven
* Calcination
* Reduction
1. ***Mixing of Precursor solution and porous oxide:*** In this step, γ-Alumina (γ -Al2O3) is taken as per quantity required. Then it crushed to 2-3 mm diameter. For precursor solution Nickel Nitrate (Ni (NO3)2.6H2O) and water was mixed till complete dissolution. Precursor Solution added to the γ-Alumina drop wise with continuous stirring by glass rod. Drop wise addition done to non-uniform attachment of precursor solution to the support.
2. ***Shaking:*** The Mixture of precursor solution and Support kept in shaking bath at ambient temperature. Then mixture shakes for 6 hour. Shaking done for uniform attachment of precursor solution in the pores of catalyst.
3. ***Evaporation:*** After shaking, evaporation done to remove excess amount of water. The evaporation done at the temperature 80°C in oil bath.
4. ***Drying in Hot Air Oven:*** After removal of excess amount of water the solution kept in the Hot Air Oven for Slow rate of drying at temperature 110°C in 12hour. Due to slow rate of drying uniformity of attachment of precursor in the pores of support.
5. ***Calcination:*** Calcination done in the open air furnace or muffle furnace at temperature 600°C for 4 hour. In this step metal oxides formed.
6. ***Reduction:*** In this step the metal oxide reduced to pure metal in the presence of Hydrogen. Supported metal Catalyst formed.
* **Calculation:**

Method of preparation: Wet-Impregnation method

Catalyst to be prepared: 5gm of Ni / γ-Al2O3 Catalyst (5% Ni)

Salt precursor available: Ni (NO3)2.6H2O

|  |  |
| --- | --- |
| **Chemical** | **Molecular weight (gm mol)** |
| Ni (NO3)2.6H2O | 290.70 |
| ϒ-Al2O3 | 101.96 |
| Water | 18 |
| Ni | 58.70 |
| Al | 26.98 |
| O2 | 16 |

Molecular weight (gm/mol) of Nickel = 58.70 gm/mol

Molecular Weight of Ni (NO3)2.6H2O = (58.70 + ((14 + (16 × 3)) × 2) + (6 × ((2 × 1) + 8)) = 290.70 gm/mol

Molecular Weight of Aluminium = 26.98 gm/mol

Molecular Weight of Oxygen = 16 gm/mol

Molecular weight of Al2O3 = (26.98×2) + (16×3) =101.96 gm/mol

Calculation of Nickel (Ni) and Gamma Alumina (γ-Al2O3):

In the catalyst 5 % Nickel should be present.

Basis is 5 gm. So the Amount of Nickel needed = 5 gm×0.05 = **0.25gm**

58.7 gm/mol of Nickel present in 290.70 gm/mol of Ni (NO3)2.6H2O

For 0.25 gm of Nickel the amount of Ni (NO3)2.6H2O required

= 290.70/58.70×0.25 = **1.238gm**

The amount of ϒ-Al2O3 required = (Basis) 5gm – (qty. Of Nickel) 0.25 gm = **4.75 gm**

The amount of water required = 10 ml.

**Flow Chart for Wet Impregnation**



Open Air Furnace / Muffle Furnace

 In Shaking Bath

Calcination (4 hr) at 600°C

Supported Metal Catalyst

Content of Metal precursor Solution with Support

Shaking (6 hr)

Reduction

Drying (12 hr) at110°C

Evaporation at 80°C

Using Hot Plate

Nickel Nitrate (salt precursor), ϒ-Alumina

Passing H2

In Hot Air Oven

In Hot Air Oven

Passing H2

Nickel Nitrate (salt precursor), ϒ-Alumina

Using Hot Plate

**Figure 1: Schematic Diagram of Wet-Impregnation Method**



**Figure 2: Catalyst after Drying in Hot Air Oven**

**Conclusion:** (Write about prepared catalyst weight obtained and colour in looks).

Experiment No: Date:

**CATALYST CHARACTERIZATION (CO-1)**

**Objective:** Characterize heterogeneous catalyst (Catalyst Characterization) –Theoretical studies: Find surface area, porosity, density, nature (acidic/basic) of catalyst and strength of active site (strong acidic/basic, weak acidic/basic), dispersion of active metal, thermal stability of catalyst, composition of catalyst, surface morphology, pore diameter, crystalline or Amorphus nature and crystal size determination

Write brief note of various catalyst characterization methods to identify following catalyst characteristics from published research paper/book.

* Surface area,
* Porosity,
* Density,
* Nature (acidic/basic) of catalyst and strength of active site (strong acidic/basic, weak acidic/basic),
* Dispersion of active metal,
* Thermal stability of catalyst,
* Composition of catalyst.
* Surface morphology,
* Pore diameter
* Crystalline or Amorphus nature and crystal size determination

Experiment No: Date:

**STUDIES OF COUNTER CURRENT FLOW PATTERN IN PACKED BED REACTOR (CO-2)**

**Objective:** Studies of counter current flow pattern in packed bed column using CO2 absorption with chemical reaction with NaOH solution.

**Apparatus:**

Packed bed bubble column reactor setup, tracer injection device, measuring cylinder (250 ml), conductivity meter, TDS meter, stop watch.

**Theory:** Solubility of major gases in water is very less. Removal of gases like CO2 or H2S or other pollutant from gas stream using water is not economical due to poor solubility of such gases in water. For such cases, absorption with chemical reaction is recommended. Removal of CO2 from gas mixture is one such problem. Various industries like fertilizer plant or methanol producing plants need removal of CO2. For the same commercially, ethanol amine or mixture of ethanol amines is used for removal of CO2. To demonstrate the concept in laboratory, here sodium hydroxide solution is used to absorb CO2.

Write various possible rate controlling steps and suitable correlations for the same for fluid-fluid non-catalytic reactions.

**Chemicals:**

Water, NaOH, CO2

**Procedure:**

* Prepare 5 liter 2 N sodium hydroxide (NaOH) solution and keep it in a suitable vessel for further use. Measure conductivity/TDS of the NaOH solution prepared.
* Arrange CO2 cylinder and arrange all piping with packed column setup. Make sure there is no leakage from anywhere.
* Start CO2 gas feed from bottom of the column and adjust the flow.
* Feed NaOH solution from top (Counter current flow) of the column and adjust its flow rate according to flow of CO2 gas.
* Set conductivity meter at the bottom of the column and measure conductivity of the NaOH solution at the bottom of the column.
* Continue experiment till steady state reading of conductivity.
* Calculate conversion and overall resistance of the reaction based on collected data.

**Observations:**

Total volume of the packed bed =

Liquid holdup of the packed bed =

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No. | Time, t, sec | Conductivity  | C, mol/L |
| 1 | 0 sec |  |  |
| 2 | 5 sec |  |  |
| 3 | 10 sec |  |  |
| 4 | 15 sec |  |  |
| 5 | 20 sec |  |  |

Final steady state value of conductivity =

Final steady state value of concentration of NaOH solution =

**Data:**  Collect data of CO2 solubility (Henry’s law constant) in 2 N NaOH solution,

Mass transfer coefficient of CO2 in 2 N NaOH solution,

Intrinsic kinetic rate constant for reaction of CO2 and NaOH

**Calculations:**

Overall conversion =

Overall resistance for reaction of CO2 with 2 N NaOH solution =

**Graphs:**

**Results:**

**Conclusion:**

**Quiz:**

1. Define enhancement factor and discuss its significance for fluid-fluid non-catalytic reactions.
2. Suggest few commercial applications of absorption with chemical reactions.

Experiment No: Date:

**STUDIES OF PACKED BED BUBBLE COLUME REACTOR (CO-2)**

**Objective:** Studies of packed bed bubble column (co-current flow pattern) using CO2 absorption with chemical reaction with NaOH solution.

**Apparatus:** Packed column setup, measuring cylinder, beaker, magnetic stirrer, conductivity meter, CO2 gas cylinder

**Chemicals:** Distilled water, 0.2 N NaOH, CO2 gas

**Theory:** Solubility of major gases in water is very less. Removal of gases like CO2 or H2S or other pollutant from gas stream using water is not economical due to poor solubility of such gases in water. For such cases, absorption with chemical reaction is recommended. Removal of CO2 from gas mixture is one such problem. Various industries like fertilizer plant or methanol producing plants need removal of CO2. For the same commercially, ethanol amine or mixture of ethanol amines is used for removal of CO2. To demonstrate the concept in laboratory, here sodium hydroxide solution is used to absorb CO2.

Write various possible rate controlling steps and suitable correlations for the same for fluid-fluid non-catalytic reactions.

**Procedure:**

* Prepare 5 liter 2 N sodium hydroxide (NaOH) solution and keep it in a suitable vessel for further use. Measure conductivity/TDS of the NaOH solution prepared.
* Arrange CO2 cylinder and arrange all piping with packed column setup. Make sure there is no leakage from anywhere.
* Start CO2 gas feed from bottom of the column and adjust the flow.
* Feed NaOH solution from bottom (Co-current flow) of the column and adjust its flow rate according to flow of CO2 gas.
* Set conductivity meter at the top of the column and measure conductivity of the NaOH solution at the top of the column.
* Continue experiment till steady state reading of conductivity.
* Calculate conversion and overall resistance of the reaction based on collected data.

**Observations:**

Total volume of the packed bed =

Liquid holdup of the packed bed =

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No. | Time, t, sec | Conductivity  | C, mol/L |
| 1 | 0 sec |  |  |
| 2 | 5 sec |  |  |
| 3 | 10 sec |  |  |
| 4 | 15 sec |  |  |
| 5 | 20 sec |  |  |

Final steady state value of conductivity =

Final steady state value of concentration of NaOH solution =

**Data:**  Collect data of CO2 solubility (Henry’s law constant) in 2 N NaOH solution,

Mass transfer coefficient of CO2 in 2 N NaOH solution,

Intrinsic kinetic rate constant for reaction of CO2 and NaOH

**Calculations:**

Overall conversion =

Overall resistance for reaction of CO2 with 2 N NaOH solution =

**Graphs:**

**Results:**

**Conclusion:**

**Quiz:**

1. Suggest suitable flow pattern for bubble column?
2. What is approximate gas and liquid holdup inside the bubble column? Can you measure it in case of given experimental setup?
3. Which type of non-idealities present in the bubble column used in experiment? Just list out the various parameters that effects the reaction.

Experiment No: Date:

**SOLID FLUID REACTION AND SCM VERIFICATION**

**Objective:** Studies of solid fluid reaction (non catalytic) using CaCO3 with HCl solution and verify SCM. (CO-3)

**Apparatus:**

Beaker, measuring cylinder (50 ml), conductivity meter, TDS meter, stop watch.

**Chemicals:** Water,Calcium Carbonate, HCl Solution,

**Theory:** Reactions involving solid as a reactant are burning reactions like combustion of coal or coke etc, recovery of metal from metal oxides or sulphides etc. Such solid-fluid reactions mechanism can be understood using SCM (Shrinking Core Model) or PCM (Progressive Conversion Model). SCM is widely accepted for many such reactions.

During S-F reactions, SCM model considers constant particle size, if one of the products is solid (like ash formation). Means overall size of the particle remains constant. Another type of SCM model is variable particle size, where no solid product formation during reaction. In such variable particle size, ash film resistance is zero.

Write various possible rate controlling steps and suitable correlations for the same for solid-fluid non-catalytic reactions for all different shape of the particles.

**Procedure:**

* Prepare 50 ml 0.5 N Hydrogen Chloride (HCl) solution and keep it in a suitable vessel for further use. Measure conductivity/TDS of the NaOH solution prepared.
* Prepare spherical shape calcium carbone CaCO3 particles of 10 mm diameter.
* Take 50 ml, 0.5 N HCl solution in a beaker.
* Add CaCO3 particle inside HCl solution and start stopwatch.
* Measure time required for complete consumption of CaCO3 particle.
* Measure concentration of HCl solution after completion of reaction.
* Repeat experiment with 7 mm and 5 mm CaCO3 particle size.
* Also repeat experiment with 6 mm, 4 mm and 2 mm hard wood beads or coal particle.
* Calculate conversion and overall resistance of the reaction based on collected data.

**Observations:**

Initial Concentration of HCl Solution:

Final Concentration of HCl Solution:

Volume of HCl solution taken

Shape and Size of particle and consumption time

|  |  |  |
| --- | --- | --- |
| Sr. No. | CaCO3 Cylindrical Particle | Wood Spherical Particle |
|  | Particle Size, mm | 100 % Consumption time, min | Particle Size, mm | 100 % Consumption time, min |
| 1 | 10 |  |  |  |
| 2 | 8 |  |  |  |
| 3 | 6 |  |  |  |
| 4 | 4 |  |  |  |
| 5 | 2 |  |  |  |

**Calculations:**

Overall resistance for reaction of CaCO3 with HCl solution =

% resistance of liquid film:

% resistance of reaction kinetics:

**Results:**

**Conclusion:**

**Quiz:**

1. Define SCM and PCM and draw schematic diagram for solid concentration profile for both cases.
2. Suggest few commercial applications of SCM models.

Experiment No: Date:

**LHHW Model Development**

**Objective:** Develop LHHW model based mechanism, a rate-limiting step, and a rate law consistent with experimental observation for catalytic reaction of the decomposition of cumene to form benzene and propylene. Theoretical Studies only) (CO-3)

**Chemicals: -**

**Theory:**

To develop rate laws for catalytic reactions that are not diffusion-limited. In developing the procedure to obtain a mechanism, a rate-limiting step, and a rate law consistent with experimental observation, we shall discuss a particular catalytic reaction, the decomposition of cumene to form benzene and propylene.

The overall reaction is

C6H5CH(CH3)2 gives C6H6 + C3H6

A conceptual model depicting the sequence of steps in this platinum-catalyzed reaction is shown in Figure below. Figure is only a schematic representation of the adsorption of cumene.

****

****

Equations (10-22) through (10-24) represent the mechanism proposed for this reaction.

The rate expression for the adsorption of cumene as given in Equation

 



Where

****

The rate law for the surface-reaction step producing adsorbed benzene and propylene in the gas phase

****





with the *surface reaction equilibrium constant* being



Typical units for *k*S and *K*S are s-1 and kPa, respectively

Propylene is not adsorbed on the surface. Consequently, its concentration on the surface is zero.

*C*P\_S = 0

The rate of benzene desorption is

****

****

the benzene adsorption equilibrium constant *K*B is just the reciprocal of the benzene desorption constant *K*DB





Because there is no accumulation of reacting species on the surface, the rates of each step in the sequence are all equal



Is the Adsorption of Cumene Rate-Limiting?



**If adsoprtion is rate controlling, so surface reaction and desorption steps are in equilibrium.**

, 



, 







, ,



, , 



Sketch a plot of the initial rate of reaction as a function of the partial pressure of cumene, *P*C0. Initially, no products are present; consequently. The initial rate is given by

 ,

Is the Surface Reaction Rate-Limiting?

Similarly develop rate expression for surface reaction control, Cumene rate law for surface reaction-limiting



The initial rate of reaction is



Is the desorption Rate-Limiting?

Similarly develop rate expression for desorption rate control,

Cumene decomposition rate law *if* desorption were limiting



the initial rate of reaction on the initial partial pressure of cumene, we again set *P*P0 = *P*B0= 0 .

If desorption limits, the initial rate is independent of the initial partial pressure of cumene.

*r*C0 = *k*D*Ct*

**Observation:**

The experimental observations of as a function of *P*C0 are shown in Figure as below.



**Calculations:**

Plot of initial rate Vs. initial pressure of cummene are as below (Plot graph using all three rate expressions and compare it with observation data.

**Conclusion:**

**Quiz:**

1. Discuss physisorption and chemisorption.
2. Explain LHHW model with suitable example.

Experiment No: Date:

**Solid Catalytic Reaction of Wastewater Treatment**

**Objective:** To carry out catalytic reaction for wastewater treatment and measure extent of degradation.

**Apparatus:** Glass beaker, flask, burette, pipette, magnetic stirrer, Visible or UV/Visible Spectrophotometer

**Chemicals:** Distilled water, synthetic dye (Methylene blue), ZnO/TiO2 catalyst,

**Theory:** Catalyst is an important part of many commercial applications. Success of solid catalytic process is reflected in hydrocarbon and large scale industries. Prepare list of ten commercial catalyst used for specific applications. Also write about various resistances present during solid-fluid catalytic reactions. Discuss about Effectiveness factor and Thiele modulus and their correlations.

**Procedure:**

* Prepare 25 ppm methylene blue (MB) solution. Measure dye concentration using visible spectrophotometer or UV/visible spectrophotometer.
* Take 50 ml of MB solution in beaker.
* Add 0.5 gm ZnO/TiO2 catalyst into solution.
* Prior to the evaluation of photocatalytic activity, test catalyst for the extent of surface adsorption.
* Start stirring in above solution with catalyst in dark place. Continue stirring for 1 hour (expected that adsorption equilibrium must have been established in 1 hour.
* Measure dye concentration using UV results suggest amount of dye removed from solution by adsorption.
* Shift the whole setup in sunlight and continue stirring for another 1 hour.
* Take 5 ml sample after 20 min, 40 min and 60 min.
* Since solar radiation in outdoor real conditions may vary even during clear sky days, so for better and reliable comparison of the results, parallel set ups were operated at the same time and hence under identical solar irradiation.
* Temperature of the test solution was maintained at atmospheric conditions.

**Data:** Methylene Blue (MB) as a probe dye. MB (C16H18ClN3S) is a basic cationic fast dye used extensively in textile industries. Its structure is depicted in following figure.



Figure : Structure of Methylene Blue

**Observations:**

* Total volume of MB solution taken = \_\_\_\_\_\_\_\_\_\_\_

**Observation Table:**

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No.  | Time | MB Concentration, ppm | % Conversion |
| 1 | t = 0 min |  |  |
|  | Adsorption Test |  |  |
| 2 | t = 60 min |  |  |
|  | Photo-catalyst Test |  |  |
| 3 | t = 80 min |  |  |
| 4 | t = 100 min |  |  |
| 5 | t = 120 min |  |  |

**Calculations:**

Find conversion

**Graphs:** Plot concentration Vs. t data

**Results:**

**Conclusion:**

**Quiz:**

1. Define effectiveness factor and discuss its significance.
2. Discuss various parameters that affects rate of reaction.

Experiment No: Date:

**Solid Catalytic Reaction of Wastewater Treatment**

**Objective:** To carry out catalytic reaction for wastewater treatment and measure extent of degradation.

**Apparatus:** Glass beaker, flask, burette, pipette, magnetic stirrer, Visible or UV/Visible Spectrophotometer

**Chemicals:** Distilled water, synthetic dye (Methylene blue), ZnO/TiO2 catalyst,

**Theory:** Catalyst is an important part of many commercial applications. Success of solid catalytic process is reflected in hydrocarbon and large scale industries. Prepare list of ten commercial catalyst used for specific applications. Also write about various resistances present during solid-fluid catalytic reactions. Discuss about Effectiveness factor and Thiele modulus and their correlations.

**Procedure:**

* Prepare 25 ppm methylene blue (MB) solution. Measure dye concentration using visible spectrophotometer or UV/visible spectrophotometer.
* Take 50 ml of MB solution in beaker.
* Add 0.5 gm ZnO/TiO2 catalyst into solution.
* Prior to the evaluation of photocatalytic activity, test catalyst for the extent of surface adsorption.
* Start stirring in above solution with catalyst in dark place. Continue stirring for 1 hour (expected that adsorption equilibrium must have been established in 1 hour.
* Measure dye concentration using UV results suggest amount of dye removed from solution by adsorption.
* Shift the whole setup in sunlight and continue stirring for another 1 hour.
* Take 5 ml sample after 20 min, 40 min and 60 min.
* Since solar radiation in outdoor real conditions may vary even during clear sky days, so for better and reliable comparison of the results, parallel set ups were operated at the same time and hence under identical solar irradiation.
* Temperature of the test solution was maintained at atmospheric conditions.

**Data:** Methylene Blue (MB) as a probe dye. MB (C16H18ClN3S) is a basic cationic fast dye used extensively in textile industries. Its structure is depicted in following figure.



Figure : Structure of Methylene Blue

**Observations:**

* Total volume of MB solution taken = \_\_\_\_\_\_\_\_\_\_\_

**Observation Table:**

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No.  | Time | MB Concentration, ppm | % Conversion |
| 1 | t = 0 min |  |  |
|  | Adsorption Test |  |  |
| 2 | t = 60 min |  |  |
|  | Photo-catalyst Test |  |  |
| 3 | t = 80 min |  |  |
| 4 | t = 100 min |  |  |
| 5 | t = 120 min |  |  |

**Calculations:**

Find conversion

**Graphs:** Plot concentration Vs. t data

**Results:**

**Conclusion:**

**Quiz:**

1. Define effectiveness factor and discuss its significance.
2. Discuss various parameters that affects rate of reaction.

Experiment No: Date:

**FIND EFFECTIVENESS FACTOR**

**Objective:** To find effectiveness factor and effect of diffusion resistance in solid catalyst.

**Apparatus:** Glass beaker, flask, burette, pipette, magnetic stirrer, Visible or UV/Visible Spectrophotometer

**Chemicals:** Distilled water, synthetic dye (Methylene blue), ZnO/TiO2 catalyst,

**Theory:** To understand working of the catalyst and reaction mechanism during reaction, LHHW model is good but very complex to use for reactor design. For the same power law model with concept of effectiveness factor is being used. Write suitable correlations for the same.

**Procedure:**

* Synthesize and store different size of solid ZnO/TiO2 catalyst particles.
* Prepare 300 ml of 25 ppm methylene blue (MB) solution. Measure dye concentration using visible spectrophotometer or UV/visible spectrophotometer.
* Take 50 ml of MB solution in four different 100 ml beaker.
* Add 0.5 gm of fine powder/1 mm/2 mm/3 mm spherical particles of ZnO/TiO2 catalyst into solution of each different beaker. Mark beaker with suitable sign to differentiate them.
* Prior to the evaluation of photocatalytic activity, test catalyst for the extent of surface adsorption.
* Start stirring simultaneously in all above beaker solution with catalyst in dark place. Continue stirring for 1 hour (expected that adsorption equilibrium must have been established in 1 hour.
* Measure dye concentration using UV results suggest amount of dye removed from solution by adsorption.
* Shift the whole setup in sunlight and continue stirring for another 1 hour. (all 4 beakers together with same time and stirring speed).
* Take 5 ml sample after 30 min and 60 min from all beakers.
* Since solar radiation in outdoor real conditions may vary even during clear sky days, so for better and reliable comparison of the results, parallel set ups were operated at the same time and hence under identical solar irradiation.
* Temperature of the test solution was maintained at atmospheric conditions.

**Data:** Methylene Blue (MB) as a probe dye. MB (C16H18ClN3S) is a basic cationic fast dye used extensively in textile industries. Its structure is depicted in following figure.



Figure : Structure of Methylene Blue

**Observations:**

* Total volume of MB solution taken = \_\_\_\_\_\_\_\_\_\_\_

**Observation Table:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No.**  | **Time** | **MB Concentration, ppm** | **% Conversion** |
| **Set I** | **Set II** | **Set III** | **Set IV** | **Set I** | **Set II** | **Set III** | **Set IV** |
| 1 | t = 0 min |  |  |  |  |  |  |  |  |
|  | Adsorption Test |  |  |  |  |  |  |  |  |
| 2 | t = 60 min |  |  |  |  |  |  |  |  |
|  | Photo-catalyst Test |  |  |  |  |  |  |  |  |
| 3 | t = 90 min, reaction time 30 min |  |  |  |  |  |  |  |  |
| 4 | t = 120 min, reaction time 60 min |  |  |  |  |  |  |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No.**  | **Set of Exp.** | **Observe overall rate of reaction** | **Thiele Modulus**  | **Effectiveness Factor** |
| 1 | Set I |  |  |  |
| 2 | Set II |  |  |  |
| 3 | Set III |  |  |  |
| 4 | Set IV |  |  |  |

**Calculations:**

**Results:**

**Conclusion:**

**Quiz:**

1. Define effectiveness factor and discuss its significance.
2. Discuss various parameters that affects rate of reaction.

Experiment No: Date:

**Demonstration of Fluidized Bed Reactor**

**Objective** To observe fluidization behaviour in fluidized bed reactor (Demonstration experiment)

**Apparatus:**

Fluidized bed reactor setup, Air-Compressor.

**Figure:**



**Theory:** Fluidization is an important phenomena and being used in different applications. Mainly fluidized bed reactors are required to increase rate of heat and mass. Many places fluidization facilitates removal of catalyst on continuous basis. Such continuous removal help in continuous regeneration of catalyst like in FCC. Fluidization is complicated phenomena and yet needs good understanding.

Write process of fluidization and derive rate of reaction for fluidized bed reactor.

**Procedure:** This experiment will provide better visualization and so understanding of the fluidization behavior.

* Close the outlet valve of compressor & start the compressor, wait until pressure is built-up. As the pressure reaches up to 3-5 kg/cm2 open the valve slightly and check for leakage.
* If gas cylinder is used directly start gas supply with incremental rate.
* If there is no leakage open it by observing the change in bed fluidization.
* Adjust the valve for constant velocity and observe the flow regime & pressure drop of the particles.

Basic Data:

* Column diameter 58 mm standard PMMA (Poly Meta Methyl Acrylic) pipe
* Packing: 1.8 – 2 mm Polypropylene granules
* Approximate Bulk Density = 0.636 g/cc
* Approximate Particle Density = 0.95 g/cc
* Approximate Voidage = 0.34
* Volume of sphere = πR3 = $πdp³/6$

**Observations:**

**Conclusion:**

**Quiz:**

1. Suggest applications of fluidized bed reactor in Chemical Industries.
2. Why it is known as fluidization? Justify it.
3. Why cyclone separation is recommended at the outlet of fluidized bed reactor?

**COMBUSTION CHARACTERISTICS**

**Objective:** To validate the combustion model for Shrinking Core Model and Progressive Conversion Model using suitable spherical particles.

**Apparatus:** Crucible, gas burner and safety devices

**Theory:** Solid-fluid non-catalytic reactions are very important for metallurgy and other solid industries. Write solid-fluid non-catalytic reactions and various rate controlling mechanisms and their suitable correlations.

**Procedure:**

* Collect three different size (i.e. 2 mm, 4 mm and 6 mm) of spherical/cylinderical shape coal particles.
* Start combustion of all different size coal particles.
* Allow it for complete combustion and measure the time required for complete combustion of each particle.
* Repeat the experiment again for all different size of particles and stop combustion at 50% time of complete combustion for respective particle.
* Similarly repeat the experiment for 25% time of complete combustion and note your observations.

**Observations:**

Density of solid particles:

 **Observation Table-I:**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sr. No. | Initial Size of Coal Particle, mm | Time require for Complete combustion | For 50% of total combustion time. | For 25% of total combustion time. |
| 1 |  |  | Final Size of Coal Particle, mm | Final Size of Coal Particle, mm | Final Size of Coal Particle, mm | Final Size of Coal Particle, mm |
| 2 |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |
| 4 |  |  |  |  |  |  |

**Calculations:**

**Use suitable correlation and compare theoretical and experimental results.**

**Results:**

**Conclusion:**

**Quiz:**

1. Draw schematic diagram of SCM and PCM.
2. Suggest three examples of SCM and PCM.

Experiment No: Date:

**FIND EFFECTIVENESS FACTOR**

**Objective:** To find effectiveness factor and effect of diffusion resistance in solid catalyst.

**Apparatus:** Glass beaker, flask, burette, pipette, magnetic stirrer, Visible or UV/Visible Spectrophotometer

**Chemicals:** Distilled water, synthetic dye (Methylene blue), ZnO/TiO2 catalyst,

**Theory:** To understand working of the catalyst and reaction mechanism during reaction, LHHW model is good but very complex to use for reactor design. For the same power law model with concept of effectiveness factor is being used. Write suitable correlations for the same.

**Procedure:**

* Synthesize and store different size of solid ZnO/TiO2 catalyst particles.
* Prepare 300 ml of 25 ppm methylene blue (MB) solution. Measure dye concentration using visible spectrophotometer or UV/visible spectrophotometer.
* Take 50 ml of MB solution in four different 100 ml beaker.
* Add 0.5 gm of fine powder/1 mm/2 mm/3 mm spherical particles of ZnO/TiO2 catalyst into solution of each different beaker. Mark beaker with suitable sign to differentiate them.
* Prior to the evaluation of photocatalytic activity, test catalyst for the extent of surface adsorption.
* Start stirring simultaneously in all above beaker solution with catalyst in dark place. Continue stirring for 1 hour (expected that adsorption equilibrium must have been established in 1 hour.
* Measure dye concentration using UV results suggest amount of dye removed from solution by adsorption.
* Shift the whole setup in sunlight and continue stirring for another 1 hour. (all 4 beakers together with same time and stirring speed).
* Take 5 ml sample after 30 min and 60 min from all beakers.
* Since solar radiation in outdoor real conditions may vary even during clear sky days, so for better and reliable comparison of the results, parallel set ups were operated at the same time and hence under identical solar irradiation.
* Temperature of the test solution was maintained at atmospheric conditions.

**Data:** Methylene Blue (MB) as a probe dye. MB (C16H18ClN3S) is a basic cationic fast dye used extensively in textile industries. Its structure is depicted in following figure.



Figure : Structure of Methylene Blue

**Observations:**

* Total volume of MB solution taken = \_\_\_\_\_\_\_\_\_\_\_

**Observation Table:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr. No.**  | **Time** | **MB Concentration, ppm** | **% Conversion** |
| **Set I** | **Set II** | **Set III** | **Set IV** | **Set I** | **Set II** | **Set III** | **Set IV** |
| 1 | t = 0 min |  |  |  |  |  |  |  |  |
|  | Adsorption Test |  |  |  |  |  |  |  |  |
| 2 | t = 60 min |  |  |  |  |  |  |  |  |
|  | Photo-catalyst Test |  |  |  |  |  |  |  |  |
| 3 | t = 90 min, reaction time 30 min |  |  |  |  |  |  |  |  |
| 4 | t = 120 min, reaction time 60 min |  |  |  |  |  |  |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No.**  | **Set of Exp.** | **Observe overall rate of reaction** | **Thiele Modulus**  | **Effectiveness Factor** |
| 1 | Set I |  |  |  |
| 2 | Set II |  |  |  |
| 3 | Set III |  |  |  |
| 4 | Set IV |  |  |  |

**Calculations:**

**Results:**

**Conclusion:**

**Quiz:**

1. Define effectiveness factor and discuss its significance.
2. Discuss various parameters that affects rate of reaction.

Experiment No: Date:

**Simulation of Solid Catalytic Reaction of Wastewater Treatment using DWSIM**

**Objective:** To carry out simulation of solid catalytic reaction for wastewater treatment and compare results.

**Apparatus:** Laptop/desktop, DWSIM (Openware Software)

**Theory:** Simulation is an important tool for Chemical Engineers. DWSIM is very good simulation software available in open environment. This OPENWARE software provides a big opportunity for all chemical engineers.

Using DWSIM and kinetic data available in open literature predict performance of the reactor for given volume of reactor. Also check affect of other operating paramesters on performance of the reactor.

**Procedure:**

(DWSIM must be installed on local desktop/laptop as per soft requirements).

* Open DWSIM and select suitable components (all reactants and products),
* Select suitable thermodynamic model for selected components.
* Build PFD (Process Flow Diagram) with suitable reactor configuration.
* Define or select suitable operating conditions of inlet stream and reactor.
* Provide all necessary data required and make sure degree of freedom must be zero.
* Carry out simulation and complete all calculations.
* Compare results with available exp data.
* Change any one operating parameter and save data and compare it.

**Data:** Methylene Blue (MB) as a probe dye. MB (C16H18ClN3S) is a basic cationic fast dye used extensively in textile industries. Its structure is depicted in following figure.



Figure : Structure of Methylene Blue

**Observations:**

* Total volume of MB solution taken = \_\_\_\_\_\_\_\_\_\_\_
* Type of reactor selected = \_\_\_\_\_\_\_\_\_\_\_
* Volume of reactor = \_\_\_\_\_\_\_\_\_\_\_\_
* Reaction temperature = \_\_\_\_\_\_\_\_\_\_\_
* Reaction Pressure = \_\_\_\_\_\_\_\_\_\_\_\_\_
* Reactant initial concentration = \_\_\_\_\_\_\_\_\_\_\_\_

**Observation Table:**

|  |  |  |  |
| --- | --- | --- | --- |
| Sr. No.  | Time | MB Concentration, ppm | % Conversion |
| 1 | t = 0 min |  |  |
| 2 | t = 80 min |  |  |
| 3 | t = 100 min |  |  |
| 4 | t = 120 min |  |  |

**Calculations:**

Find conversion

**Graphs:** Plot concentration Vs. t data

**Results:**

**Conclusion:**

**Quiz:**

1. How thermodynamic model will help in simulation environment?
2. Which contacting pattern is more preferable for simple kinetic controlled reactions?

Experiment No: Date:

**Select and design suitable column for absorption of CO2 using NaOH solution (CO-3)**

**Objective:** Select and design suitable column for absorption of CO2 using NaOH solution based on data from literature.

**Solve design problem**.

Experiment No: Date:

**HOMOGENEOUS - HETEROGENOUS REACTION (CO-2)**

**Objective:** Compare rate of reaction in homogeneous and heterogeneous phases using Ethyl week acetate-NaOH system.

**Apparatus:** Conical Flasks, 100 ml Beaker (as reactor), Magnetic stirrer, measuring cylinder, Conductivity meter

**Chemicals:** Ethyl acetate, NaOH, HCl, Benzene, Water

**Theory:** Homogeneous reactions represents pure kinetics. However heterogeneity in reaction add mass transfer resistance. Incorporation of such resistance is required for better prediction of performance.

Write correlations for rate of reactions for homogeneous and heterogeneous involving all resistances for reaction.

**Procedure:** Prepare setup of batch reactor with conductivity meter and magnetic stirrer.

Homogeneous Reaction:-

* Prepare 50 ml of 0.05 N of NaOH and 0.05 N of Ethyl acetate solution in water in separate beaker.
* Take 50 ml of NaOH solution in the reactor.
* Carefully add the 50 ml Ethyl acetate solution into the reactor.
* Immediately after addition of ethyl acetate start taking reading from conductivity meter.

Heterogeneous Reaction:-

* Prepare 50 ml of 0.05 N of NaOH solution in water and 0.05 N of Ethyl acetate solution in benzene or toluene in separate beaker.
* Take 50 ml of NaOH solution in the reactor.
* Carefully add the 50 ml Ethyl acetate solution into the reactor.
* Immediately after addition of ethyl acetate start taking reading from conductivity meter and take reading for every 5 seconds till completion of the reaction.

## Observation Table:

For Homogeneous reaction:

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr.****No.** | **Time****(Sec)** | **Conductivity, μs** | **Concentration** |
| **1** | **0** |  |  |
| **2** | **20** |  |  |
| **3** | **40** |  |  |
| **4** | **60** |  |  |

For Heterogeneous reaction:

|  |  |  |  |
| --- | --- | --- | --- |
| **Sr.****No.** | **Time****(Min.)** | **Conductivity, μs** | **Concentration** |
| **1** | **0** |  |  |
| **2** | **20** |  |  |
| **3** | **40** |  |  |
| **4** | **60** |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type** | **Concentration, mol/lit** | **t, Sec.**  | **Rate = dC/dt** | **k** |
|  | **Initial** | **Final** | **Initial** | **Final** |  |  |
| **Homogeneous Reaction** |  |  |  |  |  |  |
| **Heterogeneous Reaction** |  |  |  |  |  |  |

**Results:**

**Conclusion:**

**Quiz:**

1. Compare and differentiate homogeneous reactions and heterogeneous reactions