Koya University

Faculty of Engineering

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Exp-7

Group-D

CSTR In Series

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Aim :

To determine conductivity of components inside all three CSTR Reactor’s and use it to calculate every CSTR’s Conversion .

Introduction :

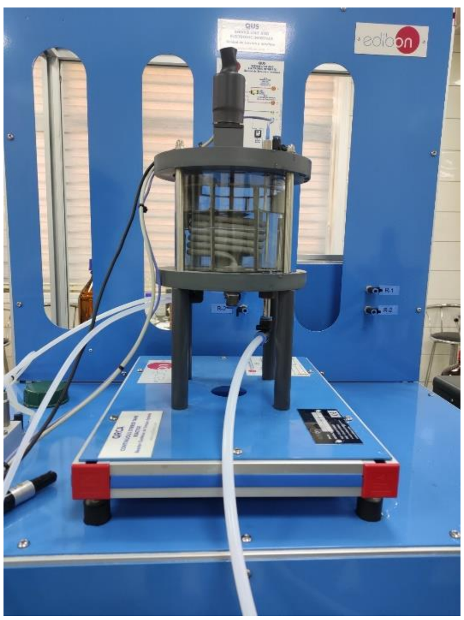
Continuous Stirred Tank Reactors (CSTRs) are essential in chemical processing due to their ability to maintain uniform mixing and steady-state operation. Unlike plug flow reactors (PFRs), where reactants move in a defined direction without back-mixing, CSTRs ensure complete mixing within each reactor, resulting in uniform concentration throughout. However, a single CSTR often exhibits lower conversion efficiency for first-order reactions compared to a PFR. To improve conversion, multiple CSTRs can be arranged in series, allowing for a stepwise reduction in reactant concentration and enhancing overall reaction efficiency.

In this experiment, three CSTRs were connected in series and arranged in a ladder configuration to facilitate smooth reactant flow. The electrical conductivity of the reacting solution was measured at each reactor to determine the concentration of key species, enabling the calculation of conversion at different stages. Conductivity measurements provide an indirect yet effective method for tracking reaction progress, as they correlate with ion concentration changes in the solution. By analyzing the conversion in each reactor, this study aims to evaluate the performance of CSTRs in series, compare experimental results with theoretical predictions, and understand the advantages of staging multiple reactors for improved chemical conversion.

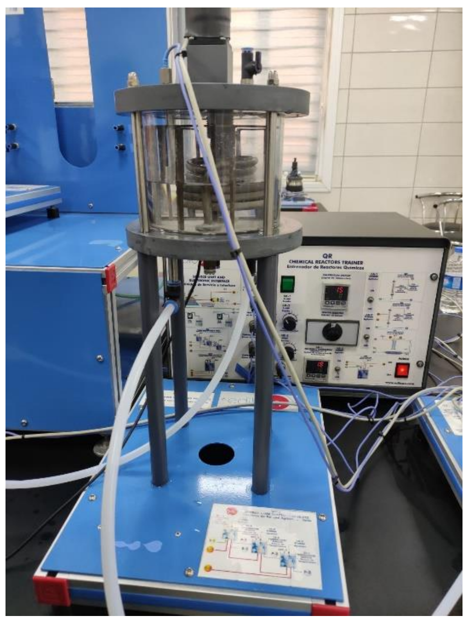
Equipment:

- ✓ Service unit
- ✓ Control interface
- ✓ Three CSTR
- ✓ Conductivity meter
- ✓ Bottles
- ✓ Digital weight
- ✓ Rubber pipes

CSTR-1



CSTR-2



CSTR-3

conductivity meter

control interface

solution's Bottles

Procedure :

1-we connect the inlet streams to the bottom of the first CSTR .

2-we install the CSTR's in a ladder configuration.

3-and about output stream we connect the first end to the bottom of the First Reactor (R-1) and the second end to the inlet of the Second Reactor (R-2) then we connect the outlet of second reactor to the inlet of the Third Reactor (R-3) then we connect the out let of the last reactor to the empty Bottle.

4-then we turn on the main switch and open the flow valve.

5- the feed does not enter until we open the vent valve due to pressure compress .

6-after opening the vent we turn on the pump to pump the solutions to the first CSTR then we turn on the stirrer.

7- the feeds enters and the conversion happens.

8-the level of the fluid stops increasing when it gets to the over flow limit which a small pipe inside first CSTR linked to the output stream.

9- after reaching to the overflow limit, we close the vent valve.

10- this work should be done for all reactors step by step.

11-during this reactions we read the electric conductivity of all reactors .

12-if we finish we turn off the pumps, stirrer and close the flow valve.

13- at the end we drain all reactor’s by opening the drain value in the bottom and vent valve at the top of the reactor.

Safety precautions:

Safety Precautions for Operating a CSTR with CH_3COOH and NaOH in a Lab

When using a Continuous Stirred-Tank Reactor (CSTR) with acetic acid (CH_3COOH) and sodium hydroxide (NaOH) as reactants, safety is crucial due to the corrosive nature of NaOH and the reactivity of the acid-base neutralization reaction. Below are key safety precautions to follow:

1. Personal Protective Equipment (PPE)

☑ Wear safety goggles – Protects eyes from splashes.

☑ Use chemical-resistant gloves – Prevents skin burns from NaOH and CH_3COOH.

☑ Wear a lab coat – Shields skin from accidental spills.

☑ Closed-toe shoes – Prevents exposure to corrosive substances.

2. Chemical Handling & Storage

- NaOH (Sodium Hydroxide):
  - Highly corrosive; can cause severe burns.
  - Store in a tightly sealed container to prevent moisture absorption.
  - Always add NaOH to water, never the reverse, to avoid heat generation.

◇ CH_3COOH (Acetic Acid):

- ➢ Can be irritating to the skin and eyes.
- ➢ Store away from strong bases and oxidizing agents.

3. Reactor Operation Safety

⚠ Check Equipment Before Use – Inspect stirrer, feed lines, and seals for leaks.

⚠ Slow Addition of Reactants – To control heat and avoid rapid reaction.

⚠ Monitor Temperature & pH – The reaction is exothermic, so overheating can occur.

⚠ Ensure Proper Ventilation – Acetic acid fumes can be irritating; use a fume hood if necessary.

⚠ Avoid Overpressure – Ensure that the reactor has a proper vent or relief system.

4. Emergency Procedures

🚨 Spill Management:

- ➢ For NaOH spills – Neutralize with dilute acetic acid.
- ➢ For CH_3COOH spills – Neutralize with sodium bicarbonate solution.
- ➢ For skin contact – Rinse immediately with plenty of water and seek medical attention if irritation persists.
- ➢ For eye exposure – Rinse with water for at least 15 minutes and get medical help.

🚨 Fire Hazard:

- Acetic acid is flammable, so keep it away from ignition sources.
- Have a fire extinguisher (CO_2 or dry chemical) nearby.

Advantage & disadvantage:

Advantages

1-Higher Conversion Compared to a Single CSTR:

When multiple CSTRs are connected in series, the overall conversion is higher than that of a single CSTR of equivalent total volume. This is especially beneficial for reactions with lower reaction rates.

2-Improved Approximations to Plug Flow Behavior:

A series of CSTRs can approximate the performance of a Plug Flow Reactor (PFR), which generally achieves higher conversions for first-order reactions.

3-Better Control of Reaction Conditions:

Each reactor in the series can operate under different conditions (e.g., temperature, pH, or catalyst concentration), optimizing the reaction step by step.

4-Flexibility in Scaling Up:

It is easier to scale up a process by adding more reactors in series rather than constructing a single large-volume reactor, which may have mixing limitations.

5-Efficient Handling of Highly Exothermic or Endothermic Reactions:

By dividing the reaction into multiple stages, heat generation or absorption can be controlled more efficiently, reducing temperature spikes and improving safety.

Disadvantages

1-Increased Equipment and Installation Costs:

Using multiple reactors instead of a single large one increases capital investment, piping, and maintenance costs.

2-Higher Space Requirements:

A series of CSTRs requires more space compared to a single reactor of the same total volume. This can be a limitation in facilities with space constraints.

3-Complex Flow Control and Maintenance:

Ensuring uniform flow distribution and preventing blockages between reactors requires careful design and maintenance.

4-Possible Decrease in Efficiency for Certain Reactions:

For zero-order reactions or cases where complete mixing is not ideal, multiple CSTRs may not provide significant benefits over a single unit.

5-Longer Residence Time Compared to a Single PFR:

While a series of CSTRs improves conversion over a single one, it still generally requires a longer residence time than a PFR for the same conversion.

Conclusion:

The experiment demonstrated the performance of three Continuous Stirred Tank Reactors (CSTRs) arranged in series, highlighting the effect of staging on conversion efficiency. By measuring the electrical conductivity at each reactor, we were able to determine reactant concentration changes and calculate conversion at different stages. The results confirmed that placing multiple CSTRs in series enhances overall conversion compared to a single CSTR, as each reactor incrementally reduces the reactant concentration.

The findings align with theoretical predictions, showing that a series of CSTRs can approximate plug flow behavior, improving conversion for first-order reactions. However, practical limitations such as flow distribution, mixing efficiency, and energy requirements must be considered when designing such systems for industrial applications. Overall, the experiment provided valuable insights into the advantages and challenges of using multiple CSTRs in series for chemical reaction engineering.

Discussion:

(Twana Dler)

1. How does placing multiple CSTRs in series affect conversion compared to a single CSTR?
Placing multiple CSTRs in series improves overall conversion because each reactor reduces the concentration of reactants step by step. In a single CSTR, the reactant concentration remains relatively high throughout, leading to lower conversion. In contrast, when multiple reactors are connected in series, the gradual reduction in concentration enhances the reaction progression, bringing the system closer to plug flow behavior, which generally results in higher conversion for first-order reactions.

2. How does the performance of CSTRs in series compare to a Plug Flow Reactor (PFR)?
A series of CSTRs can approximate the performance of a Plug Flow Reactor (PFR) when the number of reactors is sufficiently high. In a PFR, reactants move continuously without back-mixing, leading to higher conversion per unit volume for first-order reactions. While a single CSTR has lower conversion due to complete mixing, multiple CSTRs in series create a concentration gradient similar to a PFR, improving efficiency. However, to fully replicate a PFR's performance, a large number of CSTRs may be required, increasing complexity and cost.

3. What factors influence the effectiveness of CSTRs in series?

Several factors impact the effectiveness of CSTRs in series, including:

- **Number of Reactors:** More reactors generally lead to higher conversion but increase system complexity.
- **Residence Time in Each Reactor:** Sufficient residence time ensures that the reaction progresses effectively.
- **Mixing Efficiency:** Proper stirring ensures uniform concentration, preventing dead zones.

- **Flow Distribution Between Reactors:** Uneven flow rates can disrupt expected concentration profiles.
- **Reaction Order:** First-order reactions benefit more from CSTRs in series, whereas zero-order reactions may not show significant improvement.

4. In which petrochemical processes are CSTRs in series commonly used?

CSTRs in series are used in various petrochemical processes, including:

- **Polymerization Reactions:** Used in the production of synthetic rubbers, polyethylene, and polypropylene, where precise control of reaction conditions is essential.
- **Hydrolysis Reactions:** Such as the hydrolysis of esters in petrochemical feedstocks.
- **Hydrogenation Reactions:** Used in processes like desulfurization and upgrading of heavy hydrocarbons.
- **Oxidation Reactions:** For the production of chemicals like acetic acid and ethylene oxide.
- **Ammonia and Urea Production:** In intermediate reaction steps for fertilizer manufacturing.

5. What are the advantages and limitations of using CSTRs in series in industrial applications?

Advantages:

- Improves conversion compared to a single CSTR.
- Provides better control over reaction conditions.
- Allows for flexibility in scaling up processes.
- Reduces temperature fluctuations in highly exothermic reactions.

Limitations:

- Requires more space and higher capital investment.
- Increases complexity in flow control and maintenance.

- May still require long residence times compared to a PFR for certain reactions.
- Energy consumption may be higher due to multiple mixing and pumping requirements.

6. How do we identify which reactor is the first, second, and third in the CSTR series?

The reactors in the series can be identified based on their inlet connections and size:

- **First Reactor:** It has **two inlets**—both for the reactant feed . It is also **shorter** compared to the second reactor.
- **Second Reactor:** It has **one inlet**, receiving the partially reacted mixture from the first reactor. It is **taller** than both the first and third reactors, allowing for more residence time.
- **Third Reactor:** It also has **one inlet**, receiving the mixture from the second reactor, but it is **shorter** than the second reactor. It is the final stage before the product exits the system.

7. Why did we install the reactors in a ladder configuration?

We installed the reactors in a ladder configuration because we only have a pump for the first inlet to the first reactor. For the other reactors, the reactant mixture must flow naturally through gravity and pressure differences. By positioning the reactors at descending heights, we ensure a smooth flow of liquid from one reactor to the next without requiring additional pumps. This setup reduces energy consumption, simplifies operation, and maintains a steady reactant transfer between the reactors.