MASS INNOVATION PROJECT

Objective of the Project: To examine NaCl transfer from an aqueous dro into MIBK, focusing on the effects of drop size on terminal velocity and mass transfer efficiency.

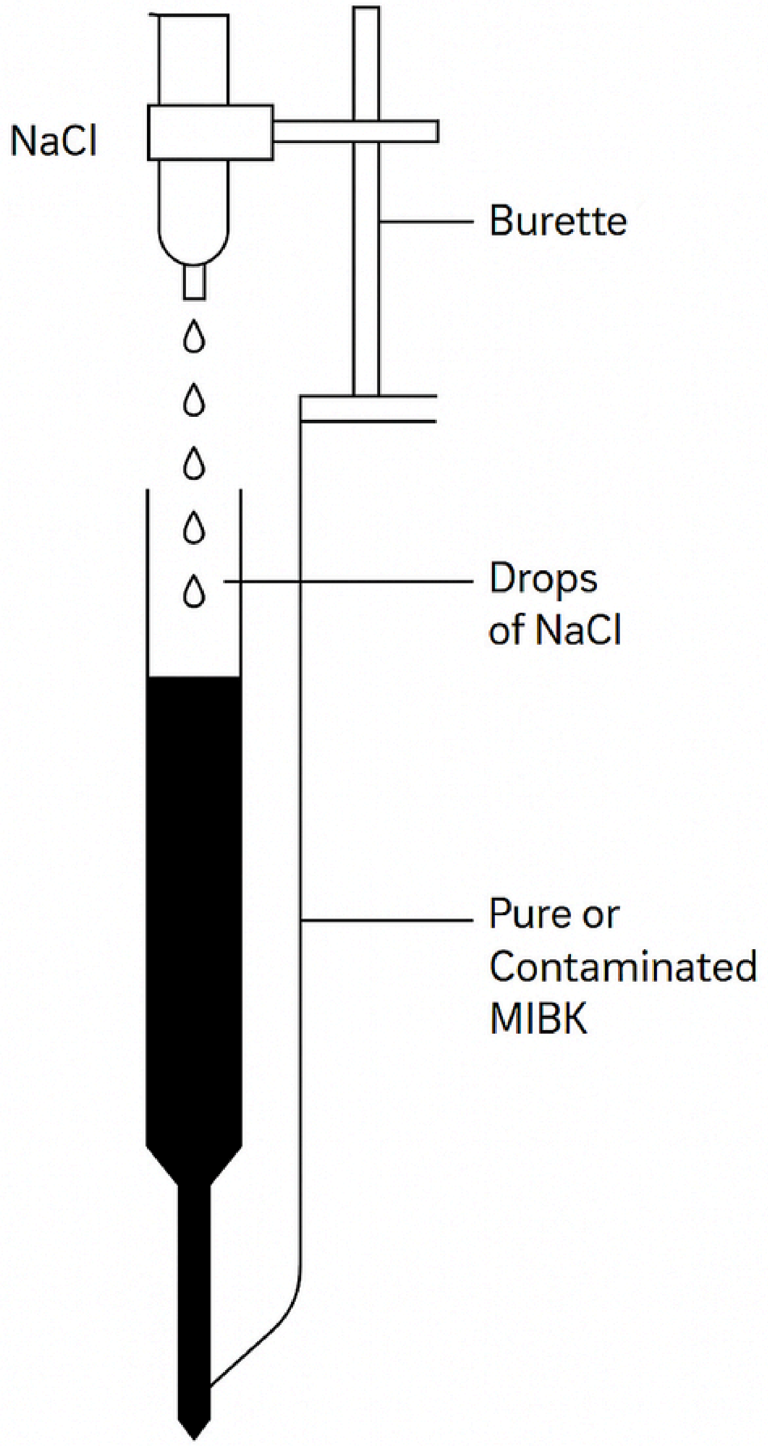
Theory: NaCl moves from the aqueous phase into MIBK through diffusion, with the transfer rate influenced by drop size, velocity, and the interfacial area. Mass transfer coefficients are derived from concentration changes.

Widely used in:

Solvent extraction
Chemical separation
Pollution recovery
Pharmaceutical & petrochemical industries

Experimental Setup

Material Required-: Glass column, burettes, pipettes, beakers, stopwatch, nozzles of varying diameters.



Chemicals: N/33 NaCl Solution (1 L)
MIBK (Methyl Isobutyl Ketone)

Experimental Setup

INNOVATION ASPECT

Redefining Single Drop Mass Transfer:

1. Safety and Environmental Benefits

- Benzene is a known carcinogen, hazardous to handle and dispose. Replacing it with MIBK, a less toxic solvent, aligns with modern chemical safety standards and green chemistry principles.

2. Experimental Robustness & Efficiency

- NaCl has well-defined conductometric properties, allowing easy and precise tracking of solute concentration.
- Eliminates titration errors (manual endpoint detection, timing lag, inconsistent mixing).

3. Broader Applicability

- The modified setup can be extended to other ionic solutes, allowing study of real industrial systems (e.g., salt extraction, wastewater treatment).

METHODOLOGY

System Configuration & Drop Dynamics

1. Experimental Setup

- Vertical glass column filled with either pure MIBK.
- Nozzles of 0.5 mm, 0.9 mm, and 1.6 mm used to generate droplets of NaCl solution.

3. Key Physical Measurements

- Drop radius (from volume assuming sphere).
- Terminal velocity (v = distance/time).
- Residence time in column.
- Drop behavior (shape, stability, breakup) visually monitored.

2. Procedure Overview:

- Prepare aqueous NaCl solution of known molarity.
- Fill syringe with solution and mount above MIBK-filled column.
- Generate drops using nozzle; ensure repeatable, uniform sizes.
- Measure fall time across known distance (e.g., 83 cm) → calculate terminal velocity.
- Collect data for each nozzle diameter (3 trials each).

METHODOLOGY

Data Analysis & Mass Transfer Calculations

1. Concentration Measurement via Conductometry

- After a set number of drops fall through MIBK, conductivity of MIBK is measured.
- Using a calibration curve, convert conductivity to NaCl concentration.
- Enables calculation of concentration difference (ΔC) across the drop path.

2. Mass Transfer Coefficient (k) and other Terms Estimation:

- Rate of mass transfer per drop: $NA = k \cdot A \cdot \Delta C$
- Surface Area, $A = 4\pi r2$ (drop assumed spherical).
- Mass transfer coefficient derived from known ΔC, residence time, and observed solute transfer.
- Log Mean Concentration Difference: $\Delta Clm = (C1 - C2)/\ln(C2/C1)$.
- Terminal Velocity (U_t):
  $Ut = \text{Time Taken}/\text{Distance Fallen}$

THEORY

The study of the shapes of moving drops has been found useful in understanding the dynamics of moving drops since the drag on the drops depends on their shapes during movement in another medium.

The shape of a liquid drop depends upon several factors such as the viscosity of the drop fluid, viscosity of the surrounding medium and the drop volume. Small drops are generally spherical. For large drops, the shape changes periodically from ellipsoidal to prolate.

Very small drops at low Reynolds number settle in a manner similar to solid spheres and the terminal velocity increases with drop size. As the drop size is further increased, due to internal circulation, the terminal velocity attains a maximum value. After this peak point, further increase in drop diameter does not result in any appreciable change in the terminal velocity. .

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$$k_m = \frac{V \cdot \Delta C}{A \cdot t}$$

$$U_t = \sqrt{\frac{4}{3}\frac{g d_p (\rho_d - \rho_c)}{C_D \rho_c}}$$

$$C_D = \frac{24}{N_{Re}}\left(1 + 0.15 N_{Re}^{0.687}\right)$$

$$\text{for } N_{Re} < 1000$$

Conductometric Estimation of NaCl:

$$\kappa = \lambda_{Na^+}[Na^+] + \lambda_{Cl^-}[Cl^-]$$

$$[Na^+] = [Cl^-] = C_{NaCl},$$

$$\kappa = (\lambda_{Na^+} + \lambda_{Cl^-}) \cdot C_{NaCl}$$

$$\kappa = 126.4 \cdot C_{NaCl} \quad (\kappa \text{ in mS/cm})$$

$$C = \frac{\kappa}{\Lambda_m^0}$$

PRINCIPLES

- **Terminal Velocity and Drop Behavior**

  As the drop falls through the continuous phase:

  - It reaches a terminal velocity where drag force balances gravity and buoyancy.
  - The shape of the drop (spherical or ellipsoidal) and internal circulation affect the velocity and transfer rate.
  - The rate of solute (NaCl) transfer is influenced by drop size, residence time, and interfacial area.

- **Conductometry-Based Concentration Measurement**

  Unlike titration, where color indicators are used to detect endpoints, conductometry measures the electrical conductivity of the solution:

  - The conductimeter is used to measure the conductivity of the continuous phase, which increases as NaCl diffuses out of the drop into the surrounding medium.
  - The conductivity of the continuous phase increases as NaCl diffuses out of the drop.
  - This provides a real-time, quantitative method to track solute concentration.
  - It allows accurate measurement of concentration without requiring manual titration steps.

RESULTS & ANALYSIS

PURE MIBK

Nozzle Dia (mm)	Drop Vol (mL)	Radius (cm)	Time (s)	Distance (cm)	Terminal Velocity (cm/s)	Conductivity (mS/cm)	NaCl (mol/L)	ΔC (mol/L)	Mass Transfer Coeff. (cm/s)
0.5	0.025	0.18	4	83	20.8	151	0.2575	0.00422	0.0103
0.9	0.045	0.22	3.565	83	23.3	163	0.2768	0.00585	0.0176
1.6	0.075	0.26	3.51	83	23.6	176	0.2985	0.0076	0.0243

RESULTS & ANALYSIS

Contaminated MIBK

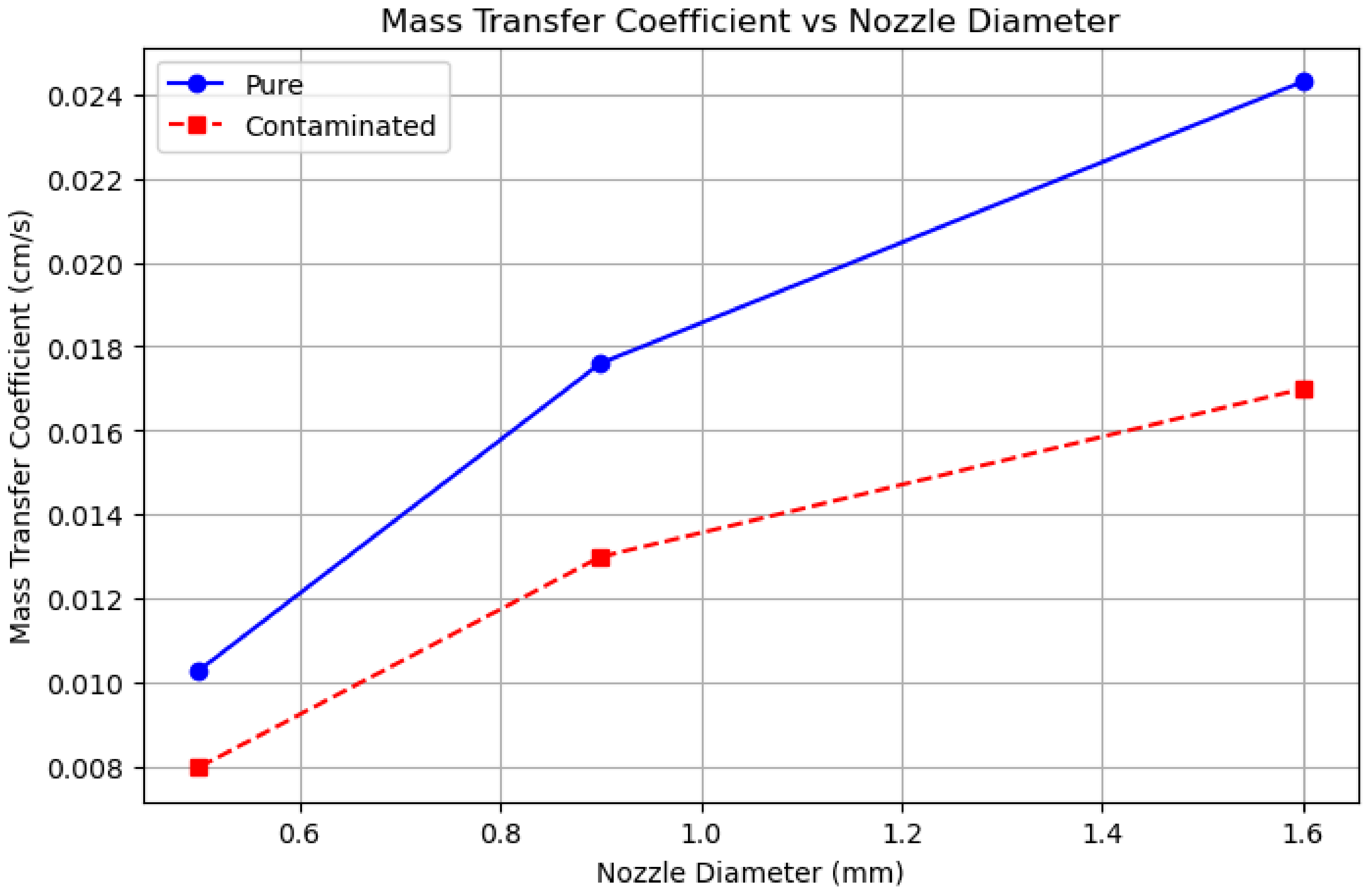
Nozzle Dia (mm)	Drop Vol (mL)	Radius (cm)	Time (s)	Distance (cm)	Terminal Velocity (cm/s)	Conductivity (mS/cm)	NaCl (mol/L)	ΔC (mol/L)	Mass Transfer Coeff. (cm/s)
0.5	0.025	0.18	4.125	83	20.1	154	0.261	0.0035	0.008
0.9	0.045	0.22	4.395	83	18.9	167	0.2838	0.0048	0.0135
1.6	0.075	0.26	4.41	83	18.8	178	0.3062	0.0055	0.0172

Pure MIBK

Nozzle Dia (mm)	Mass Transfer Coeff. (cm/s)	Rate (mol/s)	Total Mass Transferred (mol)
0.5	0.0103	1.77×10^{-5}	7.43×10^{-5}
0.9	0.0176	6.28×10^{-5}	2.01×10^{-4}
1.6	0.0243	1.57×10^{-4}	3.76×10^{-4}

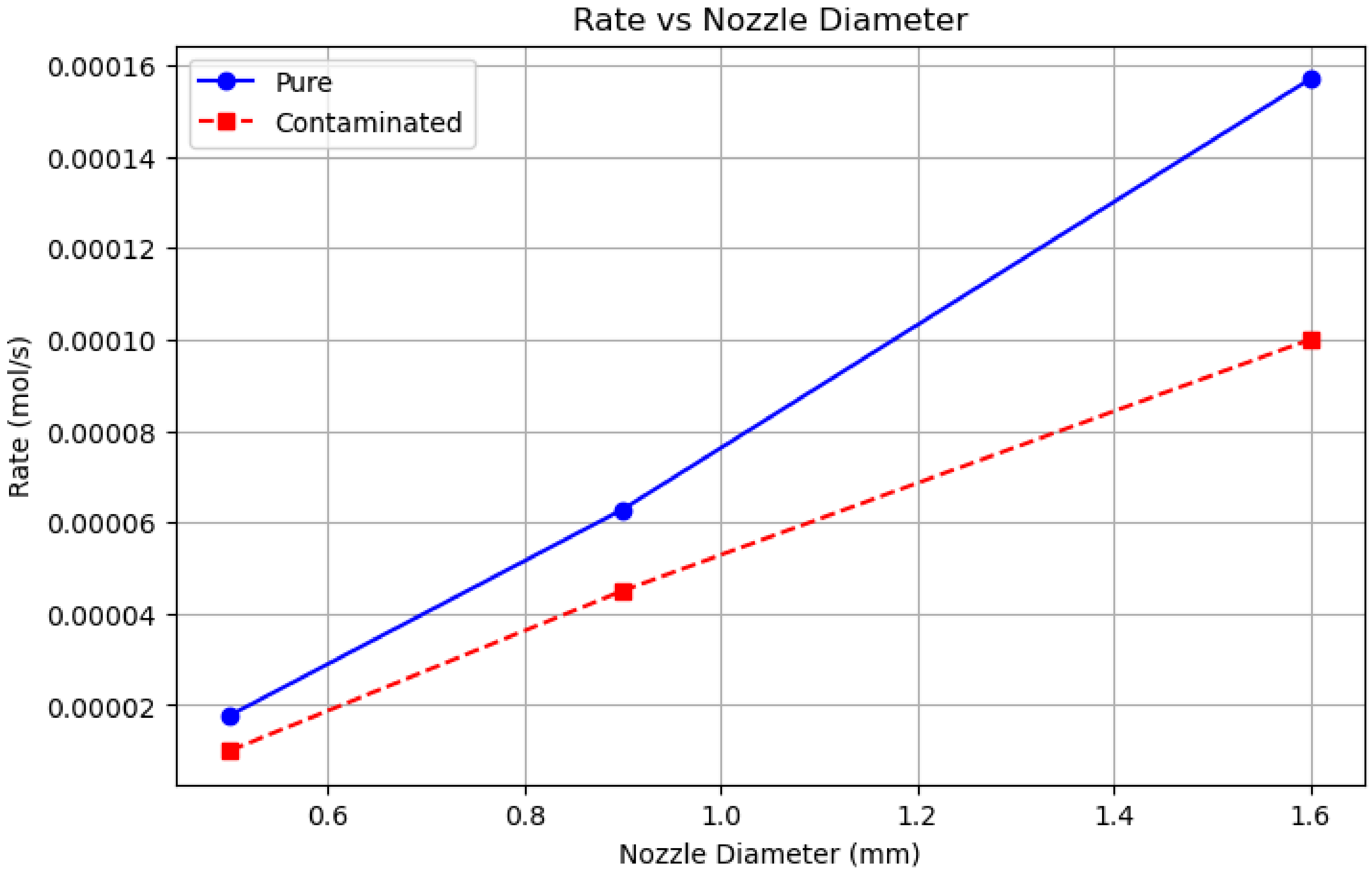
Contaminated MIBK

Nozzle Dia (mm)	Mass Transfer Coeff. (cm/s)	Rate (mol/s)	Total Mass Transferred (mol)
0.5	0.008	1.0×10^{-5}	4.0×10^{-5}
0.9	0.013	4.5×10^{-5}	1.4×10^{-4}
1.6	0.017	1.0×10^{-4}	2.6×10^{-4}



Mass Transfer Coefficient vs Nozzle Diameter

Mass Transfer Rate vs Nozzle Diameter



RESULTS & ANALYSIS

- Mass Transfer Coefficient (k):
  - Increases with droplet size (nozzle diameter). Pure MIBK consistently shows higher values than contaminated due to better diffusion and solubility.
- Rate of Mass Transfer:
  - Follows similar trend — higher in pure MIBK. Contamination lowers the rate by reducing interfacial activity.
- Relationship Between Nozzle Diameter & Transfer Efficiency
  - Larger nozzle diameters produced bigger droplets with more surface area, leading to higher mass transfer coefficients and rates. This shows that droplet size significantly affects solute transfer efficiency in both pure and contaminated systems/
- Key Insight:
  - Contamination negatively impacts all mass transfer parameters, highlighting the importance of solvent purity in such systems.

CONCLUSIONS

- The experiment successfully demonstrated the effect of droplet parameters and contamination on NaCl mass transfer into MIBK.
- Increased nozzle diameter resulted in larger droplets with higher surface area, enhancing the mass transfer coefficient and total salt transferred.
- Pure systems consistently showed higher transfer efficiency than contaminated ones, as contamination reduced ΔC and the driving force for diffusion.
- A strong correlation was observed between NaCl concentration and conductivity, validating the use of conductivity as an indirect measurement.
- Overall, the study highlights the sensitivity of mass transfer processes to both physical parameters and system purity, offering insights for optimizing similar liquid-liquid extraction setups.