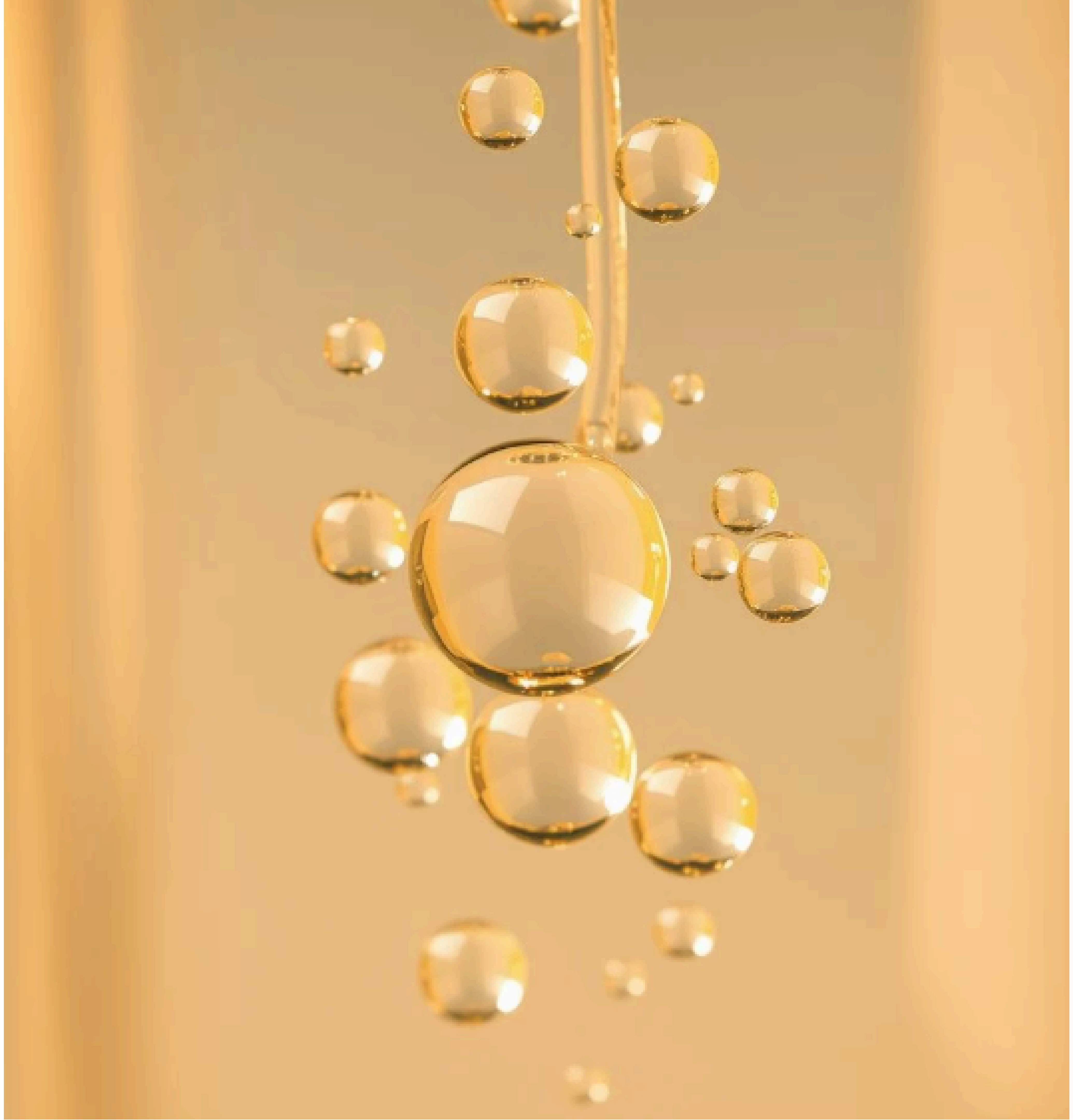
MASS TRANSFER

Group 4

Om Singh
Yash Upadhyay
Hershal
Pratyush Biswal

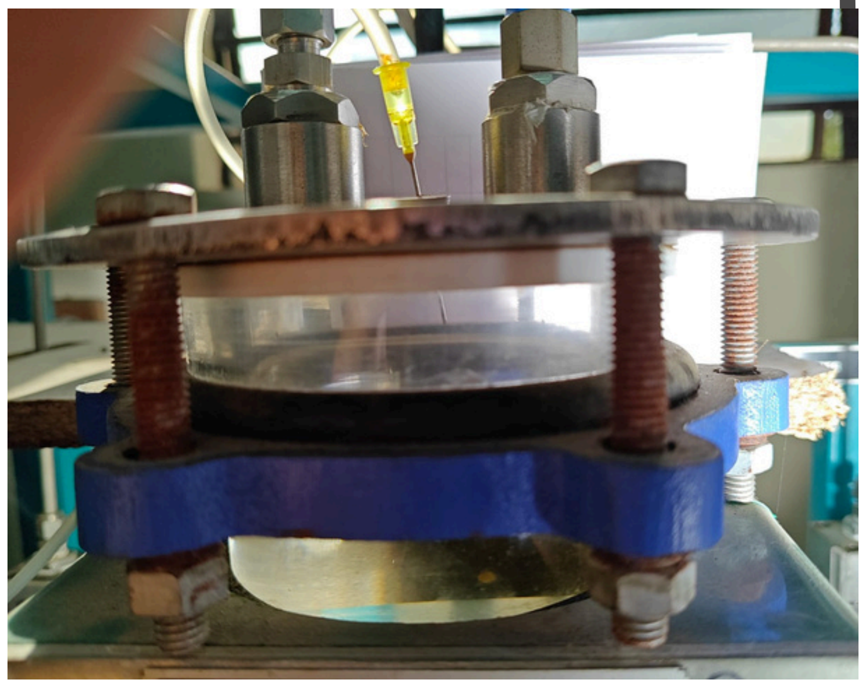


INRODUCTION TO THE PROBLEM

The core problem is to experimentally and theoretically investigate how adding a surfactant alters the mass transfer dynamics, drop behavior, and extraction efficiency in a single-drop liquid-liquid extraction system.

- In liquid-liquid extraction, the efficiency of solute transfer between two immiscible liquids depends heavily on the behavior of dispersed drops.
- The presence of surfactants changes the interfacial tension at the drop surface.
- These changes can either enhance or hinder the extraction process.

EXPERIMENTAL SETUP



- Glass Column:Filled with pure MIBK or MIBK containing acetic acid (continuous phase).
- Dispersed Phase Introduction:Aqueous acetic acid solution injected through nozzles of varying diameters to generate droplets.
- Drop Movement:Droplets descend through the MIBK medium and are collected at the base via an outlet.
- Standard lab tools: burettes, pipettes, beakers for titration.
- High-Speed Camera (Chronos 1.4): Captures rapid droplet motion,Up to 1,500 fps at 1280×1024 px resolution,High sensitivity (ISO 320–5120 color, 740–11840 monochrome)
- Lighting:High-intensity illumination ensures clear visualization for accurate high-speed imaging and analysis.

INNOVATIVE ASPECTS

- High-Speed Imaging for Drop Analysis:Utilized a Chronos 1.4 high-speed camera to precisely capture and analyze droplet formation, movement, and deformation in real time, enabling detailed study of drop dynamics and mass transfer phenomena.
- Dual Method Drop Size Measurement:Combined image analysis with theoretical calculations for drop size, allowing cross-validation and improved accuracy of experimental results.
- Systematic Study of Surfactant Effects:Investigated the impact of adding a surfactant (AOS) on drop size, terminal velocity, and mass transfer coefficients, providing new insights into how interfacial modification affects extraction efficiency.
- Integration of Experimental and Theoretical Approaches:Merged direct experimental observations with established mass transfer and hydrodynamic models, enhancing the reliability and depth of analysis.
- Advanced Visualization and Data Collection:Leveraged modern imaging and data processing techniques to obtain quantitative data that would be difficult to achieve with conventional methods.

METHODOLOGY

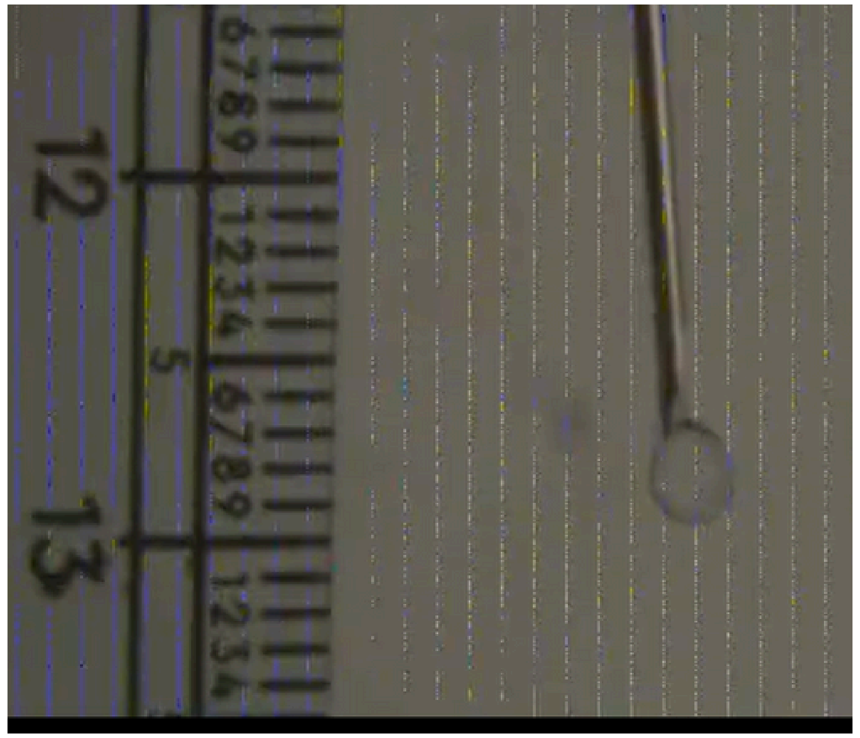
Experimental Procedure:

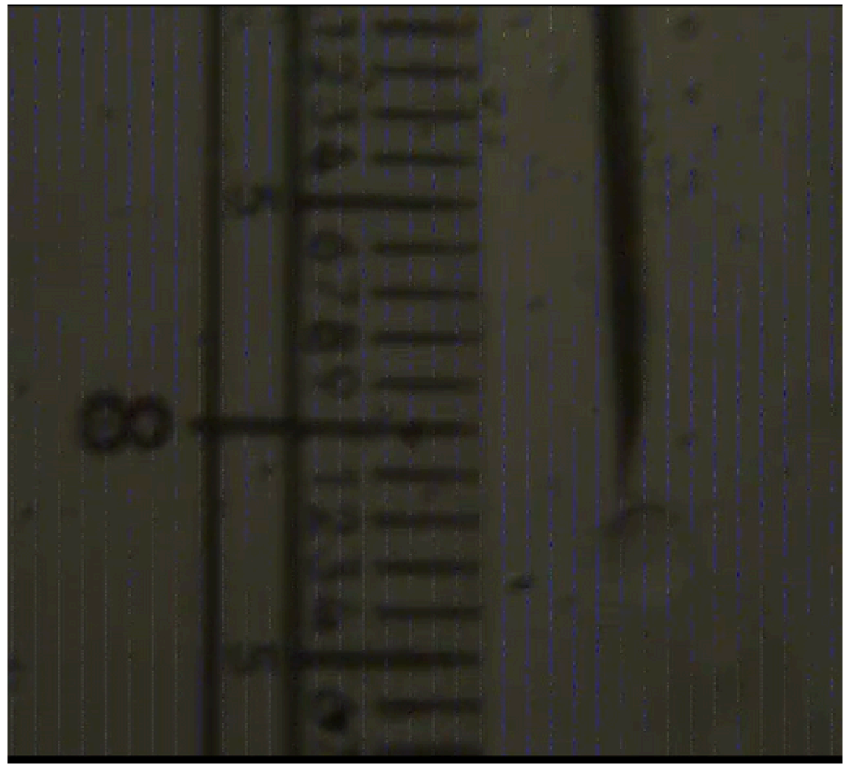
- Prepared two immiscible phases:
  - Continuous phase: MIBK (with or without acetic acid)
  - Dispersed phase: Aqueous acetic acid solution
- Introduced the aqueous phase into the MIBK column via nozzles of varying diameters to generate droplets.
- Conducted experiments both with and without the addition of surfactant (AOS) to study its effect on drop formation and mass transfer.
- Allowed droplets to descend through the column, simulating a liquid-liquid extraction environment.

Sample Collection & Analysis:

- Collected the dispersed phase at the column base after passage.
- Performed titration on collected samples to determine the extent of mass transfer (acetic acid concentration) between phases.

METHODOLOGY





MEASUREMENT TECHNIQUES:

Drop Size Determination:

- Used high-speed imaging (Chronos 1.4 camera) to capture and analyze droplet size via image analysis.
- Calculated theoretical drop size based on nozzle diameter and flow parameters for cross-validation.

Terminal Velocity Measurement:

- Timed droplet descent through a known distance in the column.

Mass Transfer Coefficient Calculation:

- Used titration data and known equations to calculate individual and overall mass transfer coefficients.

Effect of Surfactant:

- Compared results (drop size, terminal velocity, mass transfer rates) for experiments with and without surfactant addition to quantify its impact.

THEORY

Key Equations for Drop Dynamics

1. Terminal Velocity:

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

Determines equilibrium velocity of drops in the continuous phase.

2. Drag Coefficient:

$$C_d = 5 \left(\frac{N_{re}}{\sqrt{S}} \right)^{1.05} \frac{1}{\sqrt{S}\, N_{we}},$$

Accounts for flow regime and interfacial forces.

3. Dimensionless Numbers:

The Reynolds number and Weber number are defined as:

$$N_{re} = \frac{U_t\, d_p\, \rho_c}{\mu_c}, \qquad N_{we} = \frac{U_t^2\, d_p\, \rho_c}{\gamma}.$$

Characterize inertial, viscous, and interfacial forces.

THEORY

4. Surface Tension Parameter:

γ=Interfacial tension (experimentally derived)
Critical for predicting drop stability and deformation.

Parameters required to calculate γ:

- d – Diameter of the droplet
- ρ_l – Density of the dispersed (liquid drop) phase
- ρ_c – Density of the continuous phase
- l – Characteristic length scale
- τ – Characteristic time scale
- U_t – Terminal velocity of the droplet
- g – Acceleration due to gravity

5. Mass Transfer Coefficient:

$$k_L = 0.00375 \cdot U_t \cdot \left(\frac{\mu_c}{\mu_c + \mu_d}\right)$$

Predicts solute transfer rate across the interface.

6. Rate of Mass Transfer:

$$\dot{m} = k_L \cdot \pi \cdot d^2 \cdot \Delta C$$

Links drop size, velocity, and concentration gradient to extraction efficiency.

OBSERVATION

Observation Table 1: With AOS Using Needle (0.9 mm)

Sr. No.	No. of Drops	Total Time (s)
1	127	5.33
2	135	5.88
3	130	5.77
4	135	5.89

Observation Table 2: Titration Results

Total Volume Collected (ml)	Volume for Titration (ml)	Burette Reading NaOH
8.2	5	7.3

N1=0.45
V1=7.3
V2=5
N2=N1*V1/V2=0.657

Observation Table 1: Without AOS Using Needle (0.9 mm)

Sr. No.	No. of Drops	Total Time (s)
1	124	335.0
2	122	334.0
3	123	333.0
4	123	331.0

Observation Table 2: Titration Results

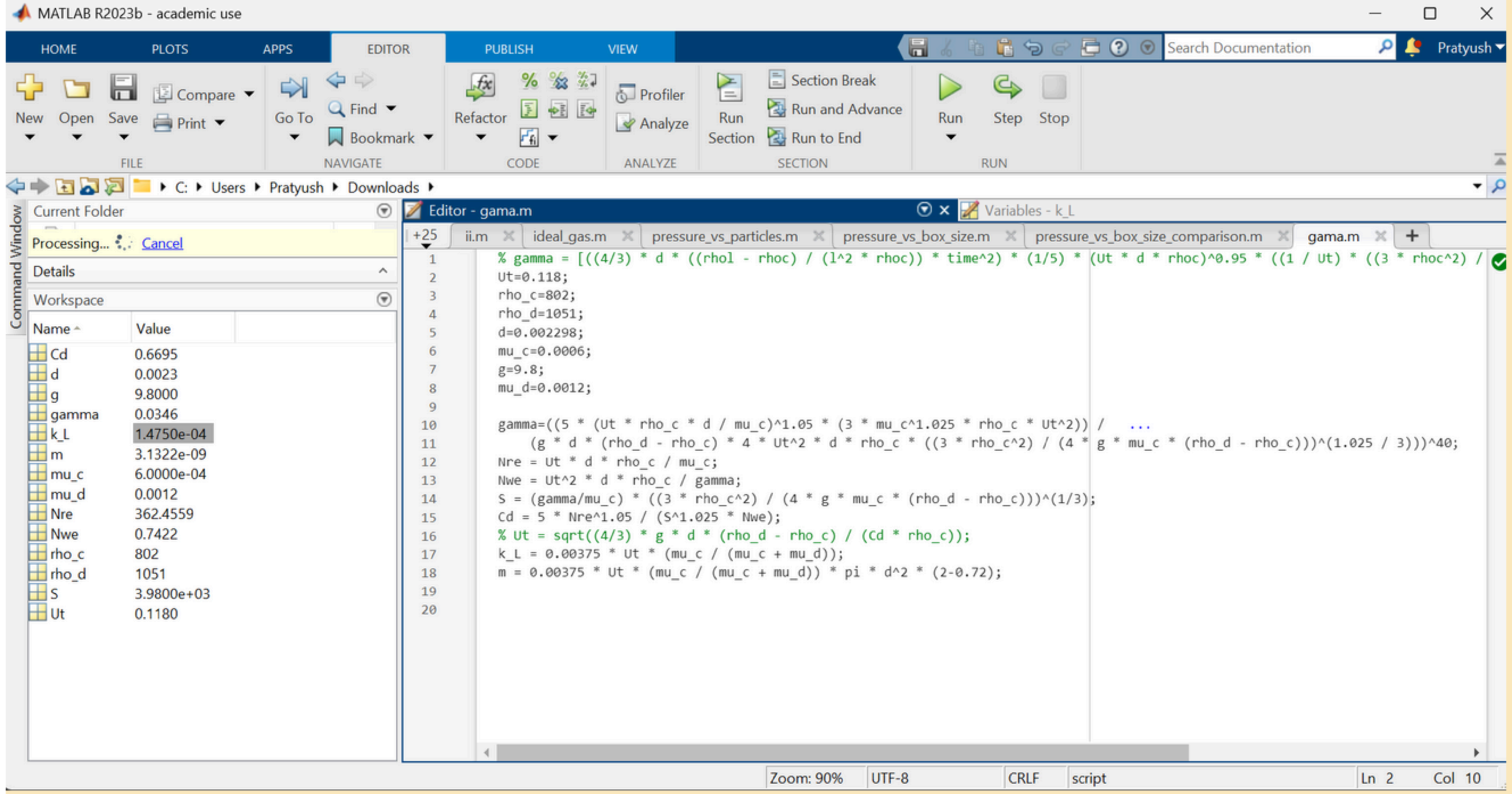
Total Volume Collected (ml)	Volume for Titration (ml)	Burette Reading NaOH
8.2	5	8

N1=0.45
V1=8
V2=5
N2=N1*V1/V2=0.72

RESULT

Without AOS

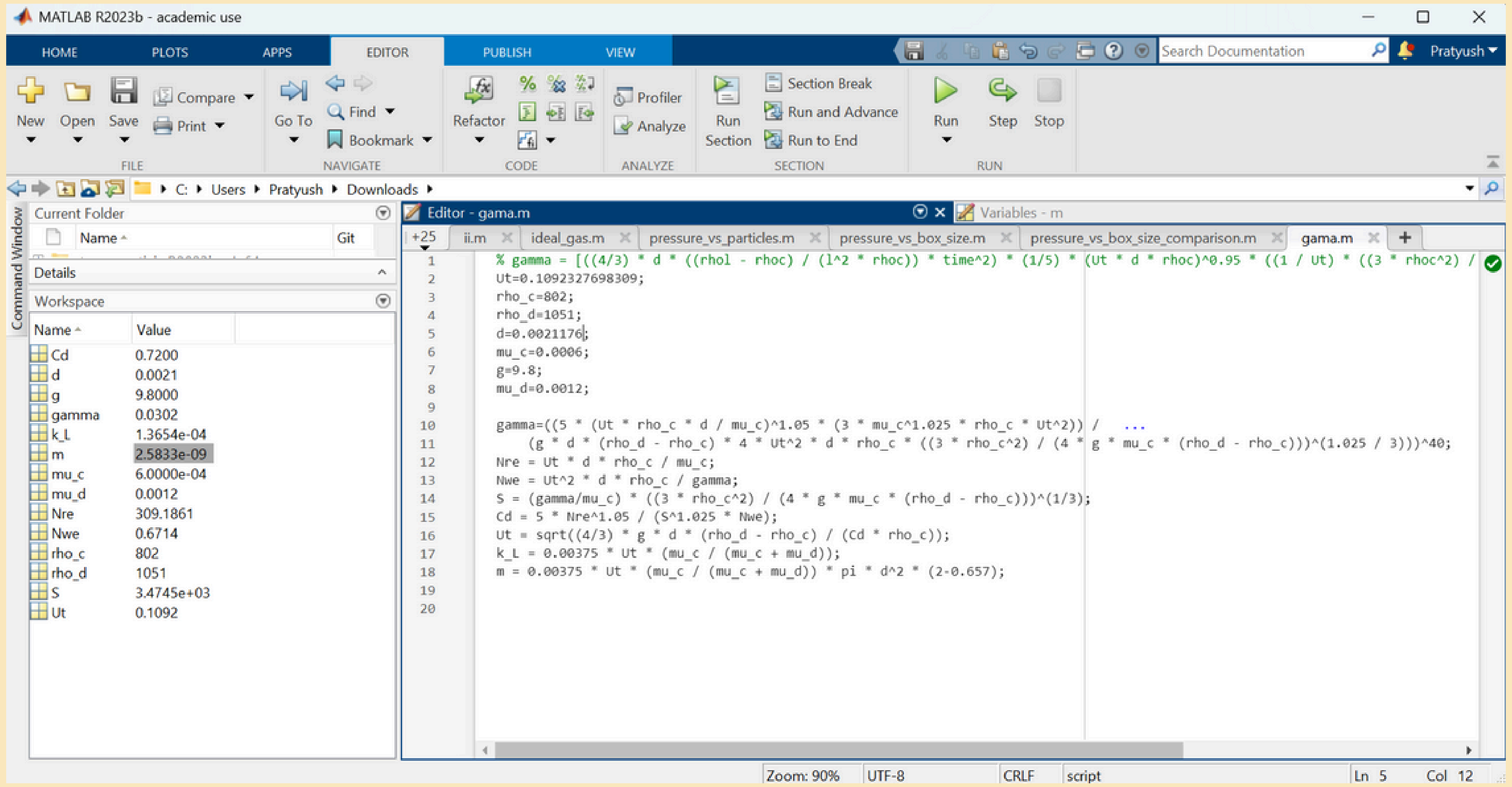
- The value of Mass Transfer Coefficent is 1.4750e-04.
- The value of rate of Mass Transfer is given by 3.1322*10^-9 mol/s.
- The value of Gamma is 0.0346 N/m



RESULT

With AOS

- The value of Mass Transfer Coefficent is 1.3654*10^-4.
- The value of rate of Mass Transfer is given by 2.5833*10^-9 mol/s.
- The value of Gamma is 0.0302 N/m



DETAILED ANALYSIS

1. Mass Transfer Coefficient

The mass transfer coefficient value decreases on adding Surfctant (to the given precision). This suggests that AOS reduce interfacial mobility and can create a barrier at the interface, hindering the diffusion of molecules.

2.Rate of Mass Transfer

Percentage decrease after adding Aos ≈17.5%.This happens due to:-

- Surfactants like AOS tend to accumulate at phase boundaries, forming interfacial films that hinder mass transfer. These films increase resistance at the interface, reducing the mass transfer coefficient. Studies have shown that the presence of surfactants can decrease mass transfer rates by up to 95.9%, depending on conditions
- Additionally, surfactants can affect hydrodynamics by altering bubble formation and movement, leading to decreased turbulence and further reducing mass transfer efficiency .

Gamma

A small decrease in Gamma (~13%) is observed with AOS.

If Gamma here refers to a dimensionless group (like interfacial tension ratio or spreading coefficient), the lower value might indicate a reduction in interfacial resistance or tension, possibly due to AOS acting as a surfactant or interface modifier.

CONCLUSION

- The addition of surfactant (AOS) significantly alters drop dynamics in liquid-liquid extraction:
- Reduces interfacial tension, resulting in smaller, more stable droplets.
- Modifies terminal velocity and internal circulation, impacting mass transfer rates.
- High-speed imaging and dual-method drop size analysis provide accurate characterization of droplet behavior.
- Theoretical models for mass transfer and drop motion align well with observed trends, validating their use for process prediction and optimization.

FUTURE WORKS

- Investigate the effects of different types and concentrations of surfactants on mass transfer and drop stability.
- Extend the study to multi-drop and continuous flow systems to better simulate industrial conditions.
- Explore the use of computational fluid dynamics (CFD) simulations for deeper insight into interfacial phenomena.
- Optimize process parameters for scale-up and improved efficiency in industrial liquid-liquid extraction operations.

THANK YOU