# Characterization of Alginate Hydrogels with Air-Plasma Surface Treatment


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## ABSTRACT


**OBJECTIVE:** To evaluate how air-plasma surface treatment modifies the physicochemical and dielectric properties of alginate–$CaCl_2$–glycerol hydrogels.

**METHODOLOGY:** Hydrogels were prepared and treated with air-plasma (1 min). Structural, swelling, porosity and dielectric properties were analyzed.

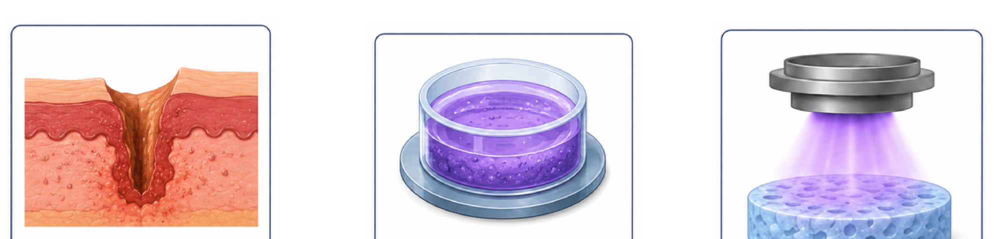
**KEY RESULTS:** Plasma increased hydrophilicity and FTIR suggested modified functional groups and altered electrical properties.

**CONCLUSION:** Air-plasma treatment demonstrated potential as an effective surface modification and characterization approach capable of altering the physicochemical and electrical properties of alginate hydrogels, supporting their future use in biomedical applications.


## INTRODUCTION

- Alginate hydrogels are biocompatible, hydrophilic and widely used in biomedical applications.
- Air plasma treatment can modifies the physio chemical and electrical properties of alginate hydrogel.
- Understanding these changes is key to determine whether this method is suitable and effective for biomedical applications.

## BACKGROUND



A chronic wound needs a moist environment for better tissue repair.

Alginate hydrogels promote healing and moisture balance.

Air plasma treatment can modify physicochemical and electrical properties.

## PROBLEM

### POOR MOISTURE RETENTION

Gauze does not maintain an optimal moist environment, which is essential for cell migration and tissue regeneration.

### TISSUE ADHESION & PAIN

Gauze can stick to the wound bed, causing pain and trauma during dressing removal and potentially damaging new tissue.

### FREQUENT REPLACEMENT

Dressings require frequent changes due to poor exudate management and saturation.

### PROLONGED HEALING TIME

Suboptimal wound environment and repeated disturbance can delay the healing process.

### INCREASED COSTS & WORKLOAD

More frequent dressing changes increase nursing time, material use, and overall healthcare costs.

## METHODOLOGY – STEP 1

The alginate hydrogel band was prepared by dissolving sodium alginate and adding glycerol, preparing calcium chloride ($CaCl_2$) solution, and adding the alginate solution drop by drop into the $CaCl_2$ solution in a Petri dish.

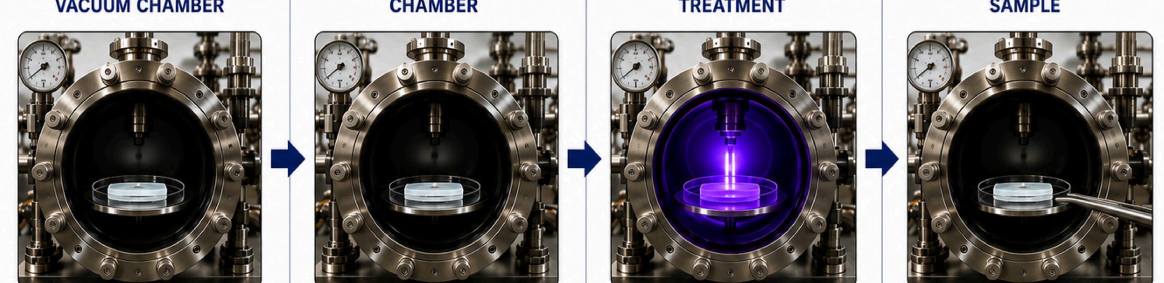
1. **ALGINATE DISSOLUTION WITH GLYCEROL INCORPORATION** — Sodium alginate was first dissolved in water under continuous stirring. After complete dissolution, glycerol was added to the solution.
2. **DISSOLVE $CaCl_2$** — Calcium chloride ($CaCl_2$) was added to deionized water and stirred until completely dissolved.
3. **ADD ALGINATE DROP BY DROP INTO $CaCl_2$ SOLUTION** — The alginate–glycerol solution was added drop by drop into the $CaCl_2$ solution in a Petri dish under gentle stirring to ensure homogeneity.
4. **CROSSLINKING** — The mixture was left to crosslink in the Petri dish, forming the alginate hydrogel band.


## METHODOLOGY – STEP 2

### STEP 2: AIR PLASMA TREATMENT IN VACUUM CHAMBER

The crosslinked alginate hydrogel band was subjected to air plasma treatment in a vacuum chamber under controlled conditions to modify its surface properties.

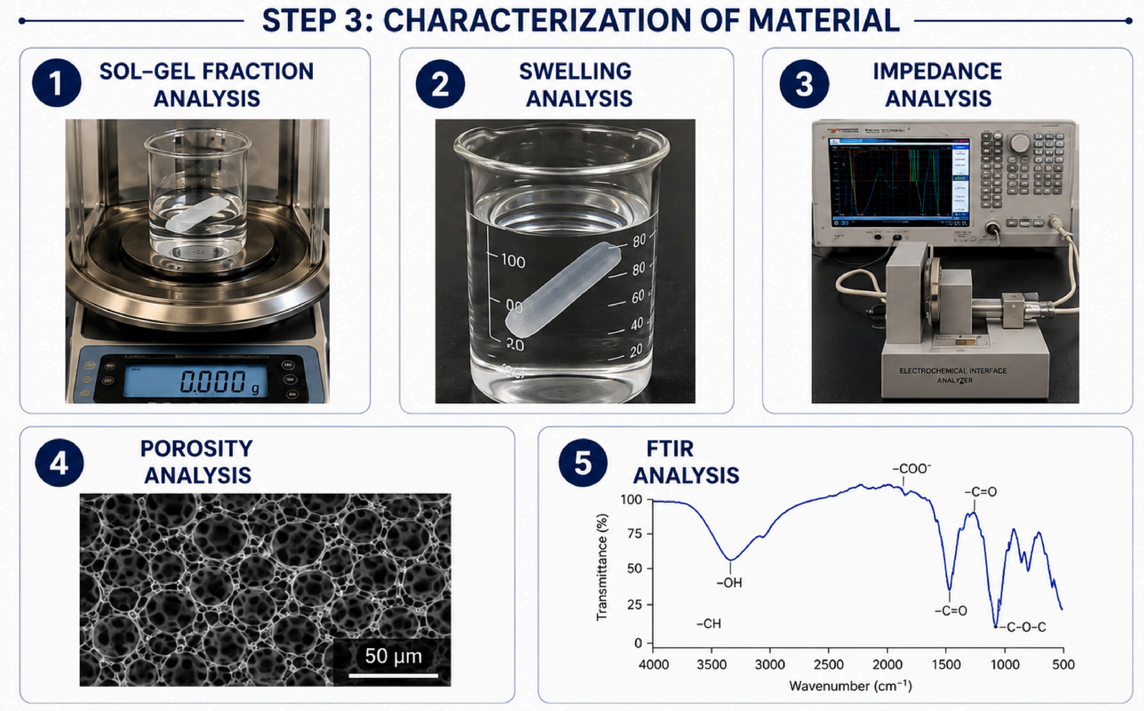
1. **PLACE IN VACUUM CHAMBER** — The crosslinked alginate hydrogel band was placed on the base inside the vacuum chamber.
2. **EVACUATE CHAMBER** — The chamber was evacuated to the desired base pressure using a vacuum pump.
3. **AIR PLASMA TREATMENT** — Air plasma was generated under controlled conditions (power, time, pressure, and gas flow). The hydrogel band was exposed to plasma.
4. **VENT AND REMOVE SAMPLE** — After treatment, the chamber was vented and the plasma-treated hydrogel band was removed using sterile tweezers.



## METHODOLOGY – STEP 3

### STEP 3: CHARACTERIZATION OF MATERIAL

1. SOL-GEL FRACTION ANALYSIS
2. SWELLING ANALYSIS
3. IMPEDANCE ANALYSIS
4. POROSITY ANALYSIS
5. FTIR ANALYSIS



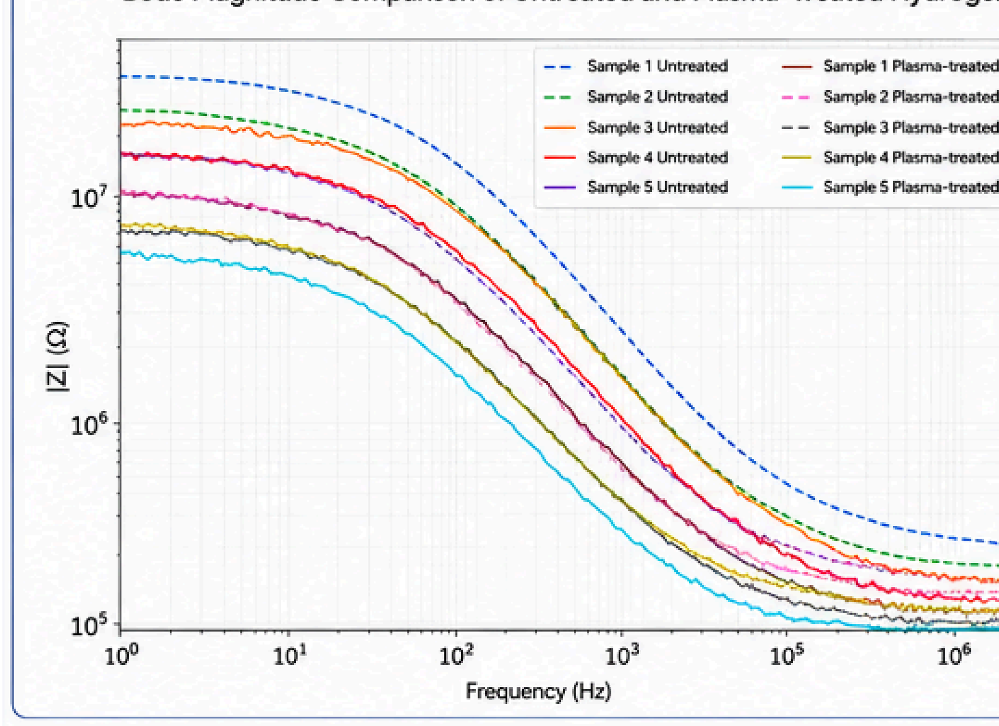

### PRELIMINARY THEORETICAL COST COMPARISON BETWEEN TRADITIONAL AND HYDROGEL DRESSINGS

| Cost Component | Parameter | Traditional Dressing (USD) | Hydrogel Dressing (USD) | Savings (USD) |
|---|---|---|---|---|
| **Nursing Time** | Time/change (hr) | 0.33 | 0.25 | — |
| | # of changes | 30 | 12 | — |
| | Wage ($/hr) | 40 | 40 | — |
| | Cost | 396 | 120 | 276 |
| **Visits** | Cost/visit | 150 | 150 | — |
| | # of visits | 10 | 5 | — |
| | Cost | 1,500 | 750 | 750 |
| **Healing Time** | Days to heal | 30 | 21 | — |
| | Cost/day | 50 | 50 | — |
| | Cost | 1,500 | 1,050 | 450 |
| **TOTAL COST** | — | **3,396** | **1,920** | **1,476** |

## RESULTS AND DISCUSSION

### 1. BODE MAGNITUDE COMPARISON

Bode Magnitude Comparison of Untreated and Plasma-Treated Hydrogels

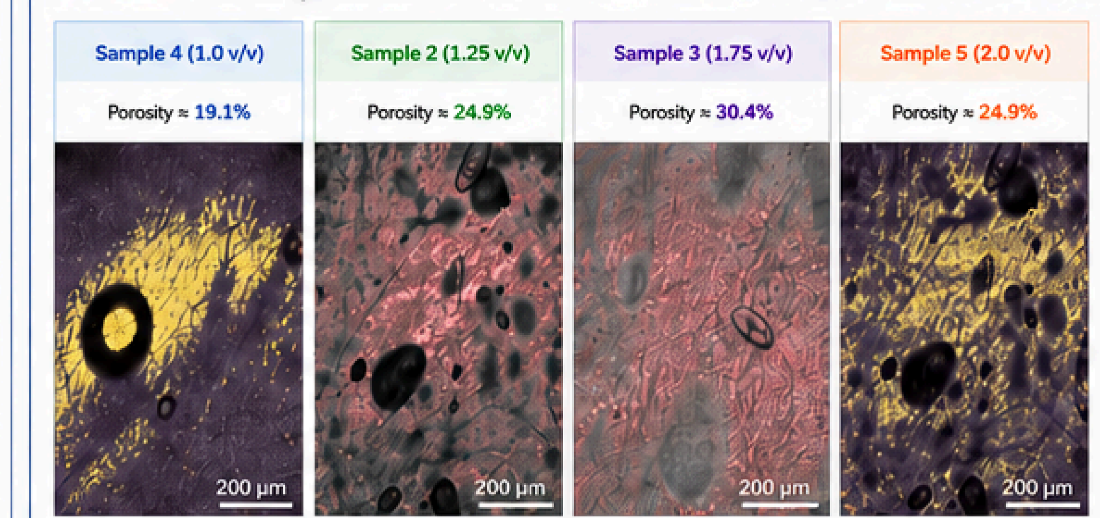



**RESULT:** The impedance magnitude decreased with increasing frequency, indicating a typical dielectric behavior, where the material exhibits higher resistance to alternating current at low frequencies and becomes more conductive at high frequencies.

### 2. POROSITY ESTIMATE

Porosity Estimate of Hydrogel Samples

Ordered by Concentration (v/v): 1.0 v/v → 1.25 v/v → 1.75 v/v → 2.0 v/v




Highlighted area: Porous regions · Highlighted area: Porous regions · Gray area: Hydrogel matrix (solid phase)

Scale bar: 200 µm

**RESULT:** Porosity increased with concentration up to 1.75 v/v (30.4%), then slightly decreased at 2.0 v/v (24.9%).

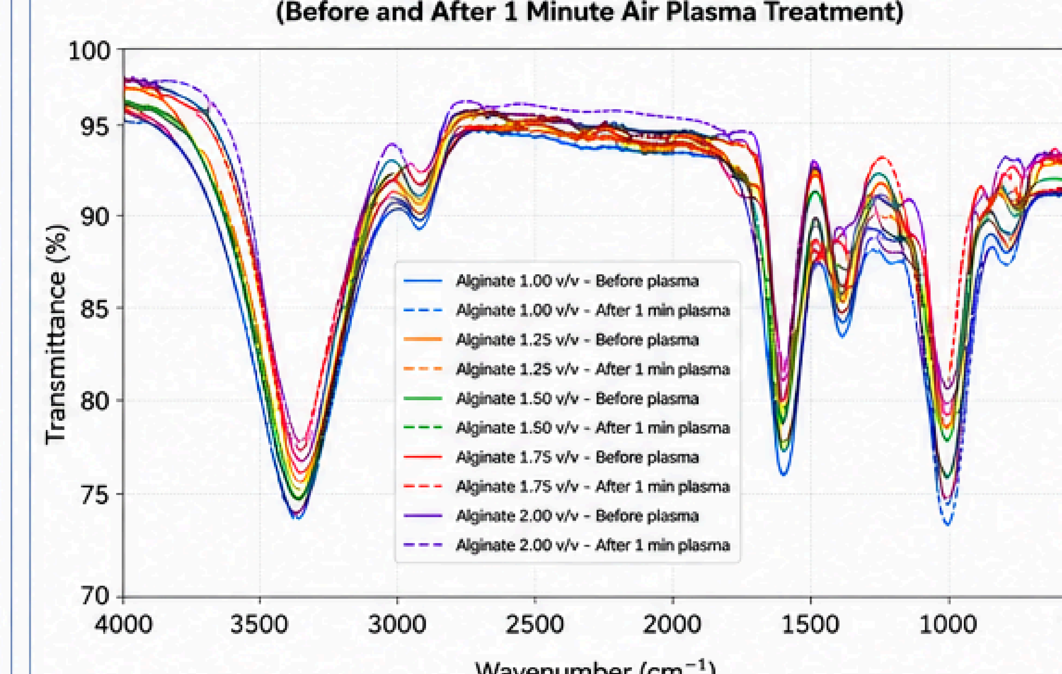
### 3. GEL FRACTION ANALYSIS

| Sample | Initial Dry Weight (g) | Final Dry Weight (g) | Gel Fraction (%) | Sol Fraction (%) |
|---|---|---|---|---|
| Sample 1 (1 wt%) | 1.00 | 0.82 | 82% | 18% |
| Sample 2 (1.25 wt%) | 1.00 | 0.86 | 86% | 14% |
| Sample 3 (1.5 wt%) | 1.00 | 0.88 | 88% | 12% |
| Sample 4 (1.75 wt%) | 1.00 | 0.90 | 90% | 10% |
| Sample 5 (2 wt%) | 1.00 | 0.92 | 92% | 9% |

**RESULT:** The gel fraction increased from **82% to 92%**, while the sol fraction decreased from 18% to 9% as alginate concentration increased.

### 4. FTIR ANALYSIS

FTIR Overlay Comparison: Alginate–$CaCl_2$–Glycerol Hydrogel (Before and After 1 Minute Air Plasma Treatment)




**RESULT:** FTIR spectra after 1 minute of air plasma treatment showed subtle changes in peak intensity and position, indicating modification of functional groups in the hydrogel.

## CONCLUSION

1. RF air-plasma treatment induced measurable surface modifications while preserving the bulk polymer network integrity.
2. FTIR analysis revealed variations in O-H and COO- absorption bands, suggesting changes in surface interactions and polarity post-plasma exposure.
3. Optical microscopy showed increased pore definition and surface irregularities in plasma-treated hydrogels.
4. Swelling behavior was modulated after plasma treatment, suggesting altered hydrophilicity and interfacial affinity with aqueous media.
5. Impedance analysis demonstrated changes in dielectric response, associated with modifications in ionic transport and surface properties.

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## FUTURE WORK

**ADDITIONAL CHARACTERIZATION TECHNIQUES**
- Quantify surface hydrophilicity changes (contact angle).
- High-resolution morphology and porosity analysis (SEM).
- Surface chemical analysis and functional group identification (XPS).

**MECHANICAL TESTING**
- Evaluate structural stability and durability under physiological conditions.

**BIOCOMPATIBILITY EVALUATION**
- Assess cytotoxicity and cell compatibility.
- Investigate bioadhesion and interaction with cells.

**ANTIMICROBIAL TESTING**
- Determine the effect of plasma treatment on antimicrobial activity and bacterial adhesion.

**IN VIVO EVALUATION**
- Conduct *in vivo* studies to assess biocompatibility and wound healing performance.

**ADVANCED APPLICATIONS**
- Controlled drug delivery
- Tissue engineering applications
- Cell compatibility
- Bioadhesion enhancement

## REFERENCES


[1] K. Y. Lee and D. J. Mooney, "Alginate: Properties and biomedical applications," *Prog. Polym. Sci.*, vol. 37, no. 1, pp. 106–126, Jan. 2012. doi:10.1016/j.progpolymsci.2011.06.003.

[2] G. T. Grant, E. R. Morris, D. A. Rees, P. J. C. Smith, and D. Thom, "Biological interactions between polysaccharides and divalent cations: The egg-box model," *FEBS Lett.*, vol. 32, no. 1, pp. 195–198, Feb. 1973.

[3] M. Laroussi, "Low temperature plasma jets: Characterization and biomedical applications," *Plasma*, vol. 3, no. 2, pp. 54–58, Apr. 2020. doi:10.3390/plasma3020006.

[4] P. K. Chu, J. Y. Chen, L. P. Wang, and N. Huang, "Plasma-surface modification of biomaterials," *Mater. Sci. Eng. R Rep.*, vol. 36, no. 5–6, pp. 143–206, Mar. 2002. doi:10.1016/S0927-796X(02)00004-9.