Department of Biomedical Engineering
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NOVEMBER 2026

Electrospun

Cellulose Acetate/ZnO Composite Membranes

towards Antimicrobial Wound Dressings

Image source:
https://www.researchgate.net/figure/Cellulose-acetate-CA-fibers-from-Nantong-Zhuhai-Kunming-Cellulose-Fibers-Co-Ltd_fig4_333150952



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Content



Image Source:
https://www.havenhealthaz.com/blog/5-types-of-wound-dressings-and-when-to-use-them/

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Introduction

Wound Dressing

A wound dressing is a sterile protective pad placed on top of a wound to:

- absorb fluid,
- prevent infection and
- stop bleeding.



Fig 1.0 : Wound Dressing

Image Source: https://www.havenhealthaz.com/blog/5-types-of-wound-dressings-and-when-to-use-them/

Introduction

Electrospinning

Electrospinning is a fabrication process that involves the use of a high voltage source to fabricate/draw out micro or nano fibres from a polymeric solution.

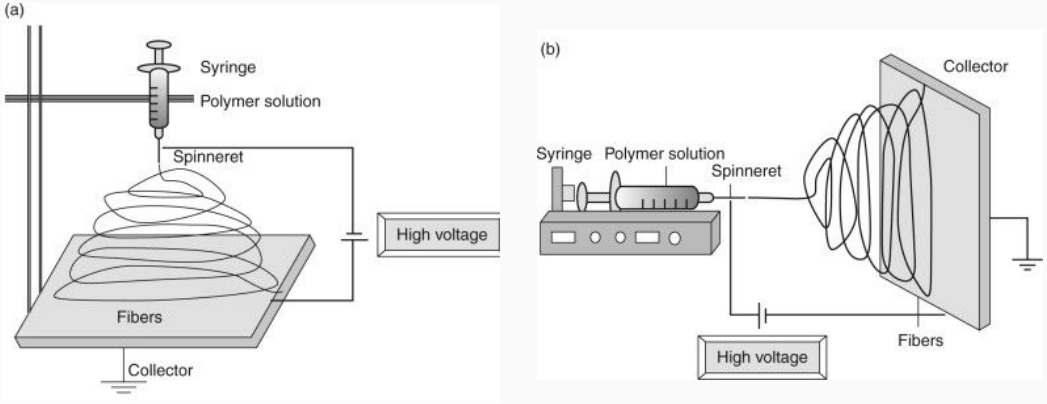


Fig 1.1 : Electrospinning process

Image Source: https://www.sciencedirect.com/topics/engineering/electrospinning-process

Introduction

Background of Study

A study of 190 patients across three hospitals in South-West Nigeria, reported that 41.6% of the patients received daily wound dressings, while 38.4% of the patients received alternate day dressing (Ogundeji & Chitha, 2025), which emphasizes the frequent need for wound dressings.

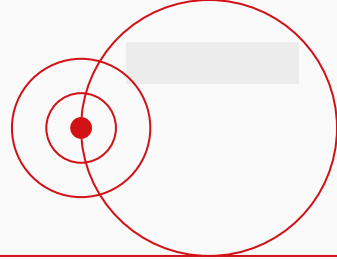
Introduction

Problem Statement

For advanced applications that utilise cellulose acetate composites, coaxial electrospinning is the preferred choice. However, the **cost of utilising coaxial electrospinning is high**, particularly in resource limited settings.

Ergo, an alternative fabrication method is paramount.

Introduction



Project Aim

To explore the **single-nozzle electrospinning process** as an alternative platform for the fabrication of cellulose acetate composites suitable for wound dressings and other biomedical applications.

Project Objectives: Solution Parameters Optimization

- To optimize the electrospinning solution parameters; **solution viscosity and polymer concentration**, for the production of cellulose acetate (CA) composite membranes embedded with Zinc Oxide (ZnO) particles.

Project Objectives: Membrane Characterization

- Thermogravimetric analysis (TGA),
- Tensile testing,
- Water absorption testing, and
- Antimicrobial efficacy against representative gram-positive organism (*Staphylococcus Aureus)* and gram-negative organisms (*Enterobacter spp.*)

Sustainable Development Goals (SDG) Targeted



Fig 1.2 : SDG 3 and 9

Image Source: https://sdgs.un.org/goals

Literature Review

A review of existing literature and gap analysis.

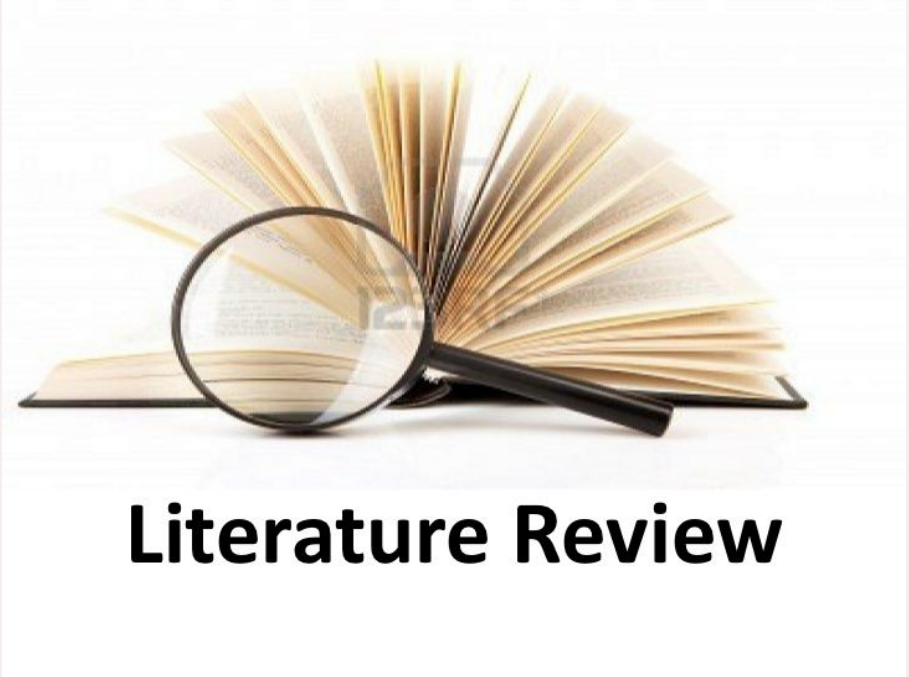


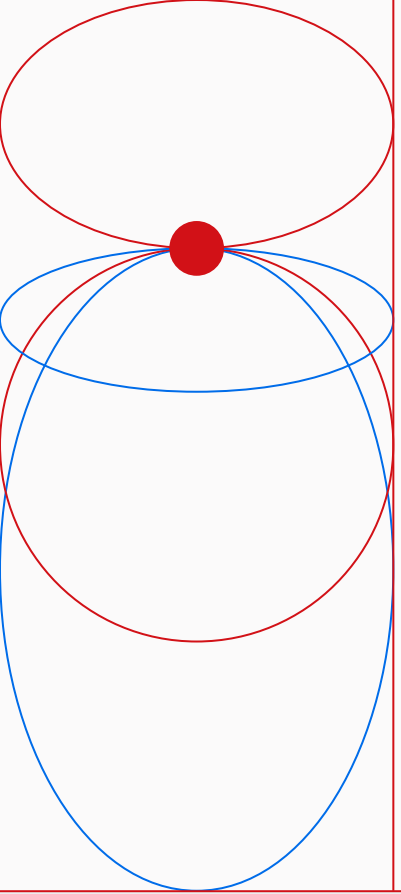
Fig 2.0 : Literature Review

Image Source:
https://afribary.com/blog/75/what-is-a-literature-review-tips-on-conducting-a-review-of-literature/

Literature Review

Table 1. Review of existing literature

Paper	**Focus**	**Deductions/Findings**	**Gap Analysis**
Ogundeji & Chitha (2025)	Cost of wound dressing in South-West Nigeria.	Wound dressing places a financial burden on patients; burn wounds had the highest weekly dressing costs.	Does not investigate **affordable alternative** wound-dressing materials.
Agarwal et al. (2008)	Biomedical applications of electrospinning.	Electrospinning produces high-surface-area nanofibres that can be functionalised for biomedical applications.	Broad review; **does not specifically investigate CA/ZnO** wound dressings.
Yan et al. (2021)	Coaxial electrospinning of cellulose acetate nanofibres.	Demonstrated CA coaxial electrospinning; solution miscibility and flow-rate ratio influenced fibre morphology.	Does **not investigate wound healing,** ZnO incorporation or biological performance.



Methodology

Methodology

Materials

- Cellulose Acetate
- Dimethylformamide (DMF)
- Acetone
- Zinc Oxide

Apparatus Used

- Single nozzle Electrospinning machine (Around 15kVA)
- 10ml syringe and 0.8mm needle
- Magnetic stirrer with heater
- Beakers

Methodology







Fig 3.0: 1st picture (Dimethylformamide, Cellulose Acetate, Acetone, white stirrer), 2nd picture (Magnetic stirring and heating machine with beaker), 3rd picture (Electrospinning machine.

Methodology

Steps Involved

- Material preparation; sanitize, measure.
- Solution formation; stir, evaluate.
- Electrospinning; prepare collection site, transfer solution, observe.
- Removal, labelling and storage.
- Safety precautions; needle sharp ends, high voltage.

Methodology







Fig 3.1: 1st picture (Beakers being dried on the Magnetic stirrer machine), 2nd picture (Measuring Cellulose Acetate), 3rd picture (Measuring Acetone).

Methodology

Fig 3.2:

1st picture (Close-up view of mixture being heated and stirred by the magnetic stirrer machine),

2nd picture (Mixture being heated and stirred by the magnetic stirrer machine).





Methodology







Fig 3.3: 1st picture (Electrospinning in progress while a directed source of light in a dark room is used to observe), 2nd picture (Electrospinning in progress in a bright room after observation), 3rd picture (Electrospinning in progress).

Methodology

Steps Involved

- Testing:
  - Mechanical test (Tensile test) at OAU, Ife.
  - Thermal test (TGA) at Zaria.
  - Water absorption test at MME lab.
  - Antibacterial test at Dr. Olukoya Research lab.

Methodology

Tensile Test

The samples were cut into a uniform length of 30.00mm, thickness of 0.50mm and width of 10.00mm.

$$Secant's\ Modulus\ at\ Ultimate\ Point\ (MPa) = \frac{Maximum\ Tensile\ Stress\ (MPa)}{Tensile\ Strain\ at\ Maximum\ Tensile\ Stress\ (mm/mm)}$$

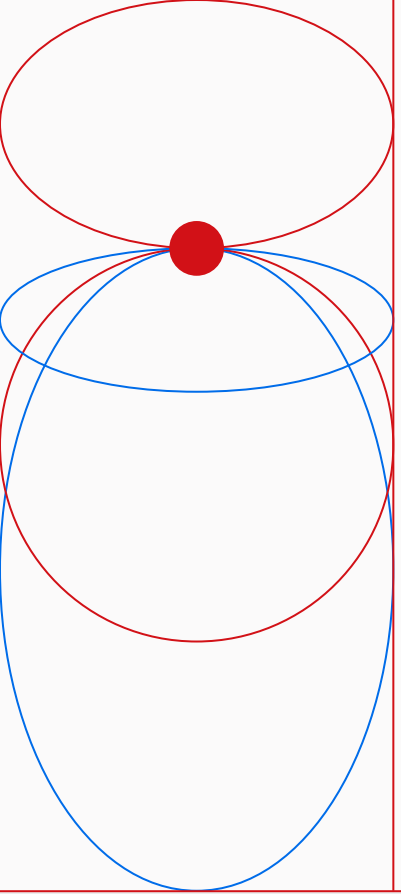
Methodology

Water Absorption Test (at 25 degrees Celsius)

$$\%\text{Weight Gain} = \frac{W_t - W_0}{W_0} \times 100$$

Where:

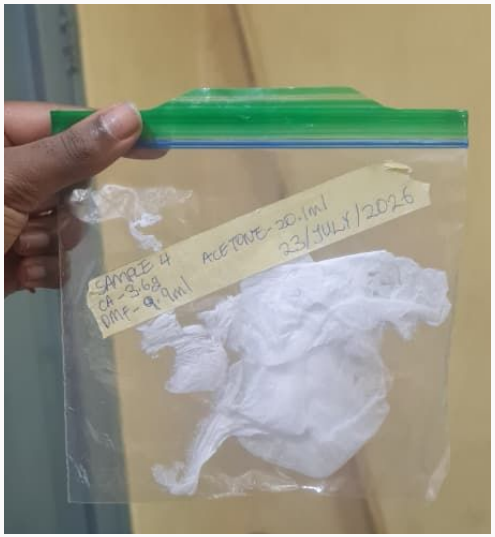
- W_0 = initial dry weight
- W_t = weight after immersion



Results

Results (Images)

Cellulose Acetate + DMF + Acetone Samples



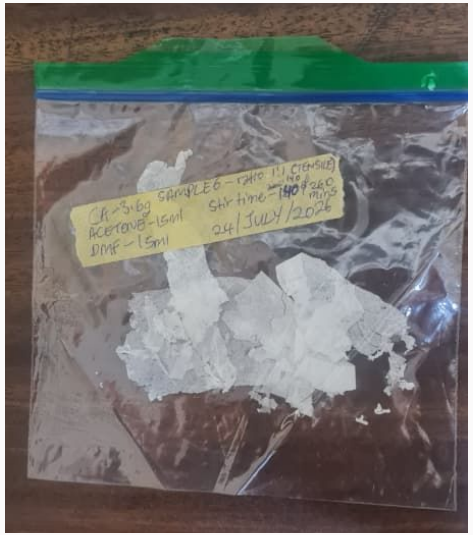
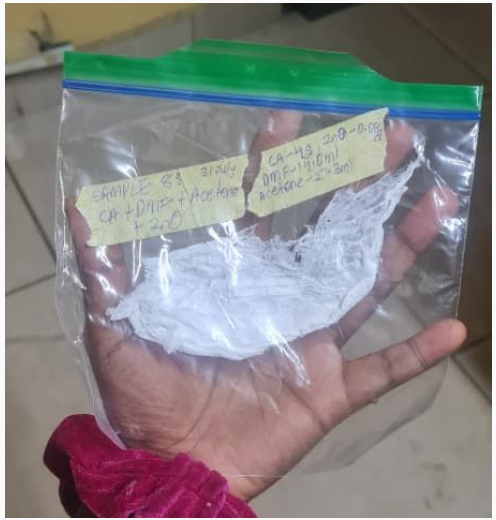


Fig 4.1: 1st picture (CA + DMF + Acetone sample with an Acetone:DMF ratio of 2:1), 2nd picture (CA + DMF + Acetone sample with an Acetone:DMF ratio of 1:1).

Results (Images)

Cellulose Acetate + DMF + Acetone + ZnO Samples



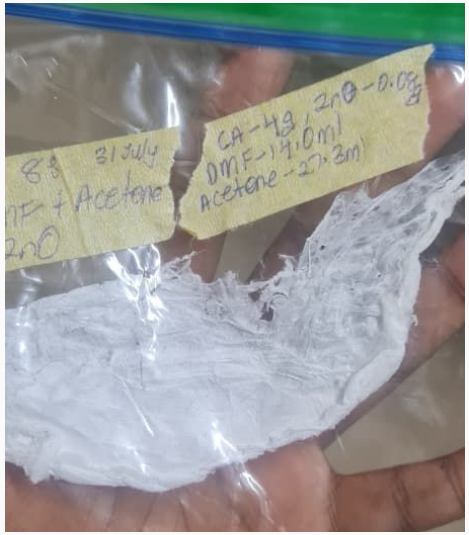


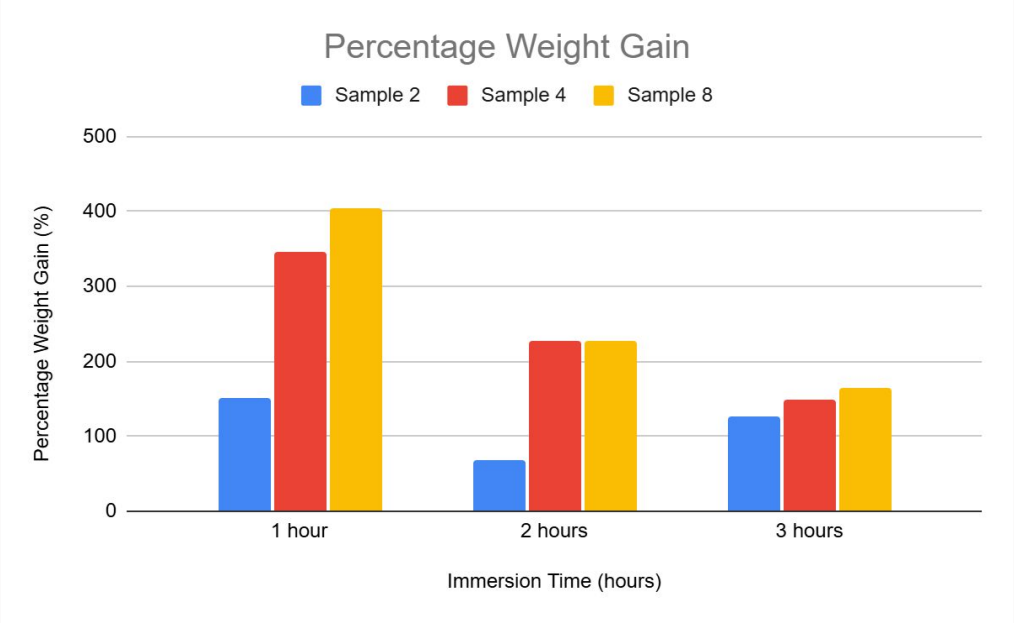
Fig 4.2: 1st picture (CA + DMF + Acetone + Zinc oxide sample with an approximate Acetone: DMF ratio of 2: 1), 2nd picture (Close-up view of CA + DMF + Acetone + Zinc oxide sample with an approximate Acetone: DMF ratio of 2: 1).

Water Absorption Test (at 25 degrees Celsius)

Table 2. Results obtained from the Water Absorption Test

Sample	Immersion Time	Dry Weight, Wo (g)	Wet Weight, Wt (g)	Water Absorbed (g)	% Weight Gain
Sample 2	1 hour	0.0239	0.0601	0.0362	151.5
Sample 4	1 hour	0.0898	0.4006	0.3108	346.1
Sample 8	1 hour	0.0207	0.1042	0.0835	403.4
Sample 2	2 hours	0.055	0.0931	0.0381	69.3
Sample 4	2 hours	0.0417	0.1366	0.0949	227.6
Sample 8	2 hours	0.0175	0.0574	0.0399	228
Sample 2	3 hours	0.0175	0.0395	0.022	125.8
Sample 4	3 hours	0.0248	0.0617	0.0369	148.8
Sample 8	3 hours	0.0202	0.0536	0.0334	165.3

Water Absorption Test (at 25 degrees Celsius)

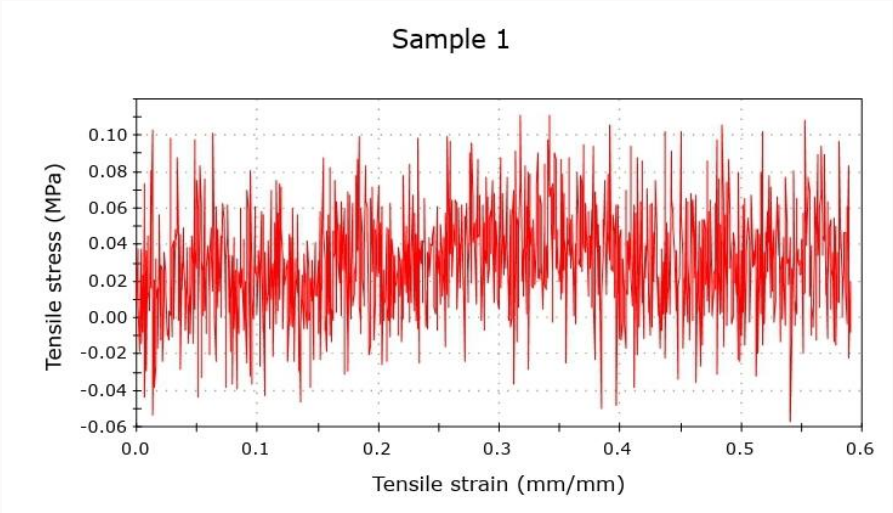


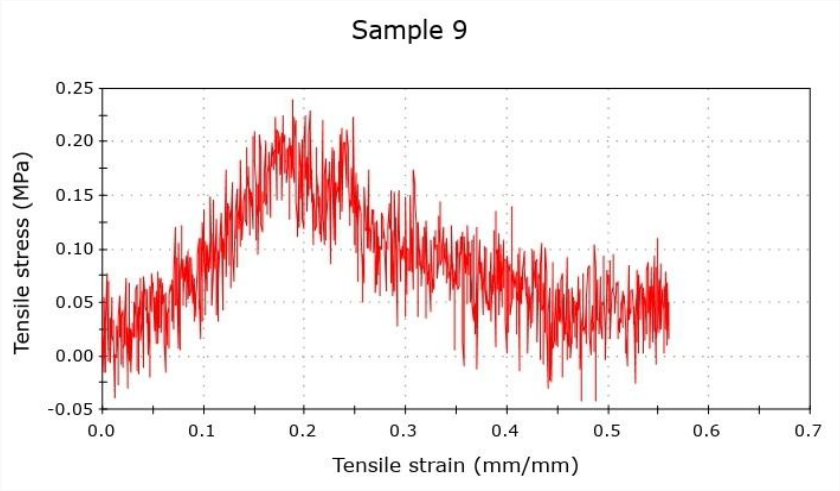
Tensile Test

Table 3. Tensile Test results of Pure Cellulose Acetate Sample and the CA sample with Zinc Oxide at key points

Sample	Load at Maximum Tensile Stress (N)	Extension at Maximum Tensile Stress (mm)	Maximum Tensile Stress (MPa)	Tensile Strain at Maximum Tensile Stress (mm/mm)	Secant's Modulus at Ultimate Point (MPa)
Sample 1 (Pure CA with 0%wt Zinc Oxide)	0.55615	10.25006	0.11123	0.34167	0.32555
Sample 9 (CA with 2%wt Zinc Oxide)	1.19453	5.65006	0.23891	0.18834	1.26850

Tensile Test (Stress-Strain Curves)





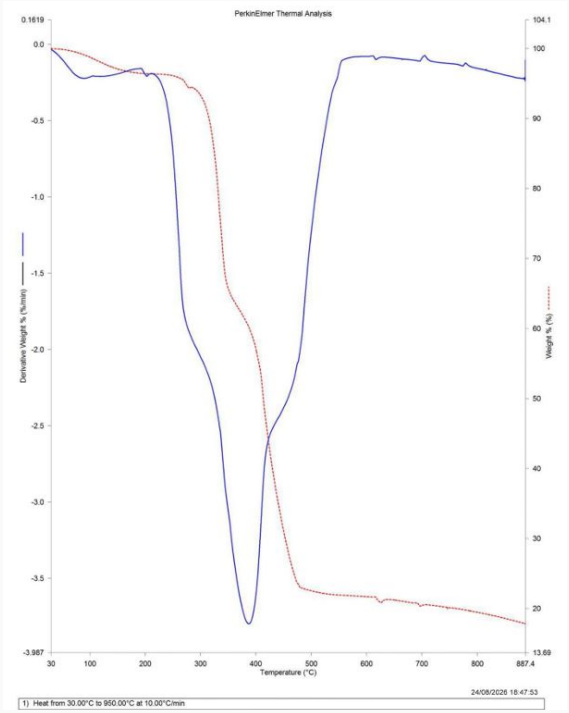
ThermoGravimetric Analysis (TGA) Test

Table 4. TGA Result for Sample 1 and 9 showing initial weight and the approximate temperature at which 5% decomposition of the fibres commenced and the DTG peak temperature

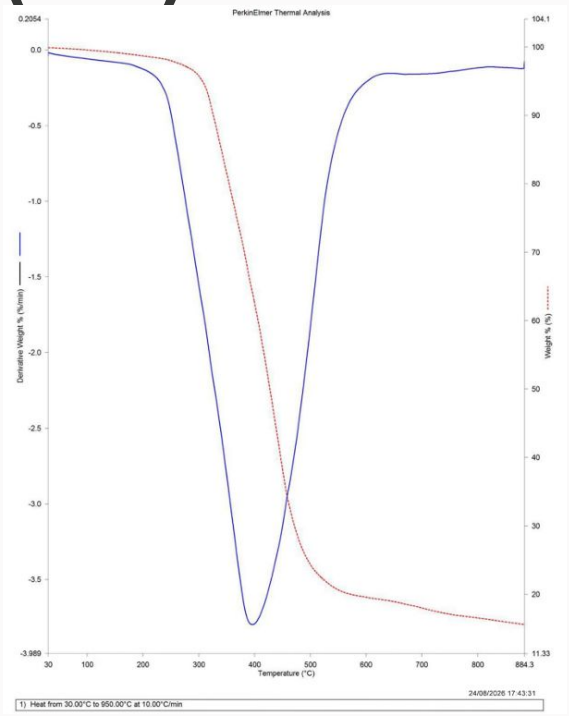
Sample	Initial weight (mg)	5% weight loss (mg)	Approximate Temperature at which 5% Decomposition of Fibres Commenced (°C)	Temperature of Maximum Decomposition Rate; DTG Peak (°C)
Sample 1 (Pure CA with 0%wt Zinc Oxide)	14.294	0.715	251	387
Sample 9 (CA with 2%wt Zinc Oxide)	14.103	0.705	264	395

Results

ThermoGravimetric Analysis (TGA) Test



Sample 1



Sample 9

Antimicrobial Activity - Agar Diffusion Test

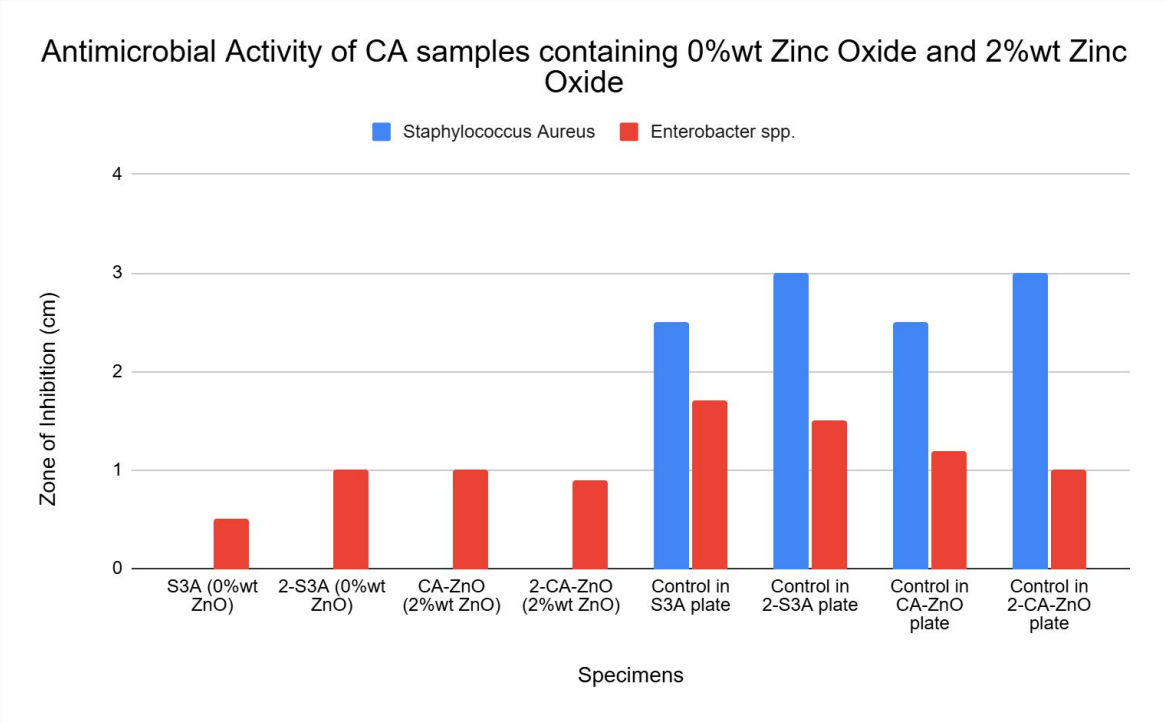
- **S3A** - Sample 3 which contains Pure Cellulose Acetate with 0%wt Zinc Oxide (ZnO)
- **2-S3A** - Duplicate of Sample 3 which contains Pure Cellulose Acetate with 0%wt Zinc Oxide
- **CA-ZnO** - Sample 10 which contains Cellulose Acetate with 2%wt Zinc Oxide
- **2-CA-ZnO** - Duplicate of the CA-ZnO sample which contains Cellulose Acetate with 2%wt Zinc Oxide

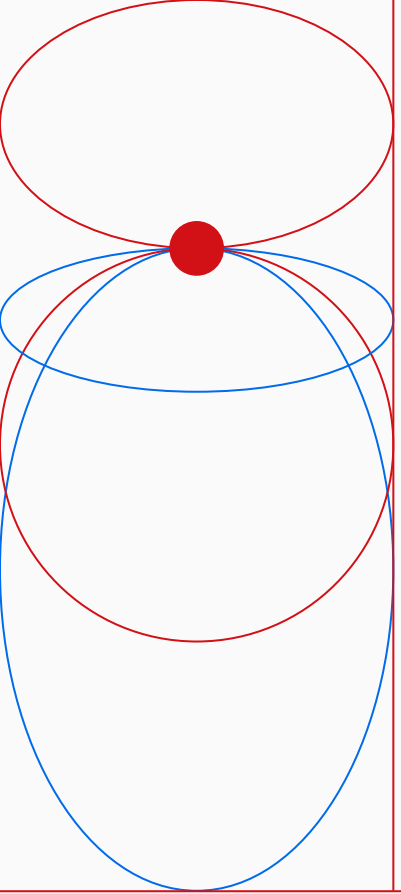
Antimicrobial Activity - Agar Diffusion Test

Table 5. Zone of Inhibition

	Zone of Inhibition for ***Staphylococcus Aureus*** (cm)	Zone of Inhibition for ***Enterobacter spp.*** (cm)
S3A (0%wt ZnO)	0.0	0.5
Control in S3A plate	2.5	1.7
2-S3A (0%wt ZnO)	0.0	1.0
Control in 2-S3A plate	3.0	1.5
CA-ZnO (2%wt ZnO)	0.0	1.0
Control in CA-ZnO plate	2.5	1.2
2-CA-ZnO (2%wt ZnO)	0.0	0.9
Control in 2-CA-ZnO plate	3.0	1.0

Antimicrobial Activity - Agar Diffusion Test





Discussion, Recommendation & Conclusion

Discussion - Water Absorption Test

From the water absorption test, Sample 8 which had Zinc oxide added to it was shown to have the highest water absorption rate over time.

Thereby, showing that the **addition of Zinc oxide** could potentially **increase the absorption rate** of the electrospun cellulose acetate wound dressing.

Sample 2 and 4 contain the same materials in the same composition; CA, DMF and Acetone.

The Acetone:DMF ratio of 2:1 was proven to be the best for fabrication, given the methodology and materials.

Discussion - Tensile Test

The Cellulose Acetate sample with Zinc Oxide could withstand **more load** at its maximum tensile stress as opposed to the sample without Zinc Oxide. The sample with Zinc Oxide also had a higher **maximum tensile stress** and **Secant's Modulus** at Ultimate point.

The **extension** at maximum tensile stress and tensile strain at maximum tensile stress of the sample with Zinc oxide were **lower** than that of the Sample without Zinc Oxide.

These results conform to existing study; Ghosh et al. (2023).

Discussion - TGA Test

5% decomposition of the pure cellulose acetate fibers with 0% zinc oxide started at 251°C while for the cellulose acetate fibers with 2% Zinc oxide, it started at 264°C.

Therefore, the incorporation of Zinc Oxide into the scaffold **does not significantly affect the thermal stability** of the scaffold.

These results conform to existing study; Ghosh et al. (2023).

Discussion - Antimicrobial Test

There was **no detectable antibacterial activity** for both samples against the **Staphylococcus Aureus**, whereas **measurable inhibitory activity**, albeit relatively small, was observed against the **Enterobacter spp.** Isolate.

However, the Enterobacter spp. results displayed variations between replicates, particularly with the S3A, so **further** and **repeat testing** is recommended to strengthen the conclusion drawn.

Recommendation

- Optimization of the single-nozzle electrospinning **machine parameters** such as voltage, working distance, flow rate, etc.
- Comprehensive **characterization** of fabricated membranes; SEM, FTIR, quantitative antimicrobial test, more replicates for Agar test, etc.
- Evaluation of functional performance under **physiological conditions**.
- Investigation of higher nanoparticle loadings and biocompatibility assessment prior to increased loading.

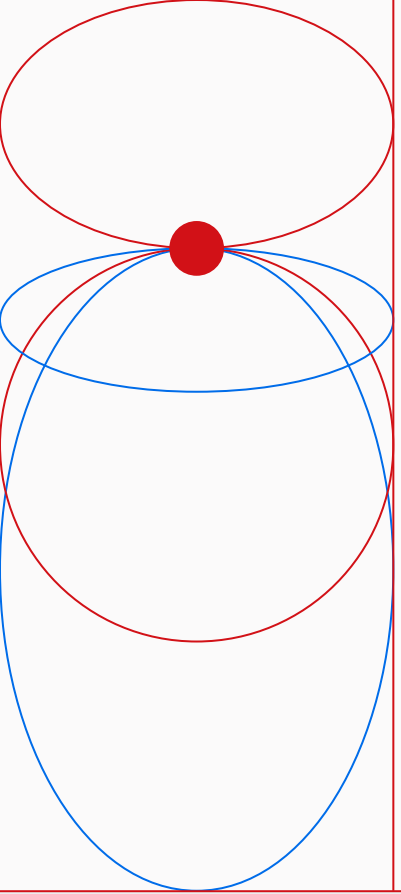
Conclusion

This project achieved its aim by **successfully fabricating** electrospun cellulose acetate membranes and identifying the processing conditions required for reproducible membrane production.

The knowledge generated through this investigation offers valuable insight into the optimization of electrospinning solution parameters and provides a strong experimental foundation for **future advancements** in **electrospun biomaterials research.**

References

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Thank you