Next-Gen Smart Materials: Thermo-Responsive and Conductive 3D Printable Polymer Gels for Diverse Applications

Engineering Goal

The goal of this project was to design and develop a smart polymer gel that has novel properties, such as responsiveness to temperature around 37°C (human body temperature), as well as flow, leveling, and water release behaviors which could be tailored for use in low-cost syringe 3D printers. After polymer synthesis and characterization, gels were evaluated for use in various industrial and biomedical applications.

Introduction

Smart Polymer Gels are a versatile class of phase-changing materials that respond to stimuli like temperature. They can retain large amounts of water and are biocompatible, enabling potential biomedical applications. **Smart gel materials can also be tailored for properties like thermo-responsiveness, rheology, conductivity, and mechanical integrity.**

3D printing has significant potential to revolutionize the biomedical industry and personalized medicine. Printing human body structures for implants and artificial tissue growth can allow for the use of specialized materials and customizable designs according to the patient's needs, as well as faster production of complex parts. Additionally, government agencies and major clinical institutions have significant interest in 3D printing medical models for doctors to practice before surgery to increase the rate of success.

Smart Gel Synthesis

Compound	Favorable Properties
Sodium Alginate, N-isopropylacrylamide (NIPAM) Ammonium Persulfate, Tetramethylethylenediamine (TEMED), Calcium Chloride	• Biocompatibility / Non-Toxicity • Gel-Forming Ability • Thermo-Responsive • Water Retention • Phase Transition Ability
Graphene	• Exceptional Conductivity • Ultra-Lightweight • Increased Toughness & Flexibility

Table created by finalist using Powerpoint, 2026

Customization of Material Properties:

Mechanical integrity: can adjust strength by crosslinking with ions

Rheology: can control flow behavior by manipulating the ratio of alginate and NIPAM

Conductivity: can introduce conductivity by adding varying graphene levels to gel formulation

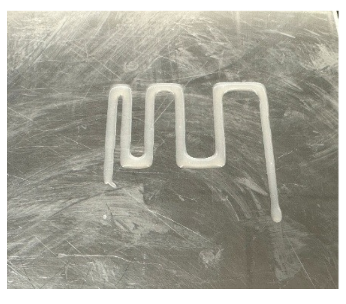
Lower Critical Solution Temperature (LCST): can adjust LCST range to body temperature by changing NIPAM amount in the gel formulation

Based on studies of the gel's deswelling behavior, DSC, and viscosity, 6%Al-4%NIPAM is the best formulation for 3D printing

Application 1: 3D Printing

Photo taken by finalist, 2025

23°C



40°C

Photo taken by finalist, 2025

Once the gel is heated during / after 3D printing, it solidifies to maintain structures designed using CAD software

Photo taken by finalist, 2025

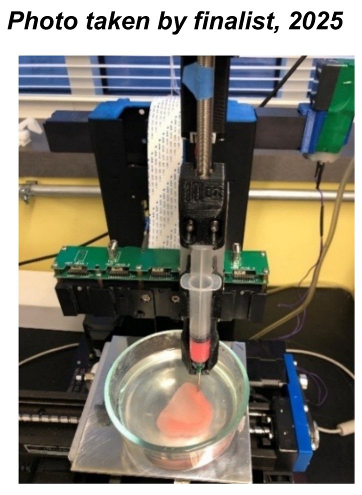


Photo taken by finalist, 2025

- Prototype model organ and tissue printing using Hyrel syringe extrusion printer
- 3D shapes form crosslinks with a prepared calcium chloride medium and successfully retain shape

The smart gel can be economically printed on a low-cost printer priced ~ $8K, compared to commercially used gel printers that can cost over $500K

Application 2: Drug Delivery

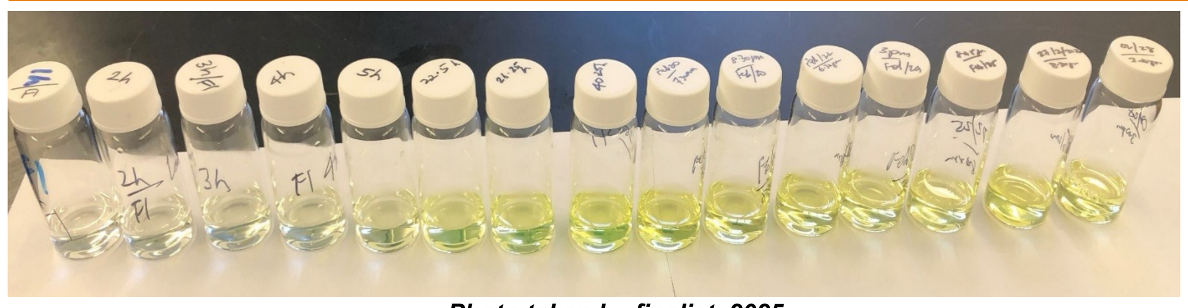
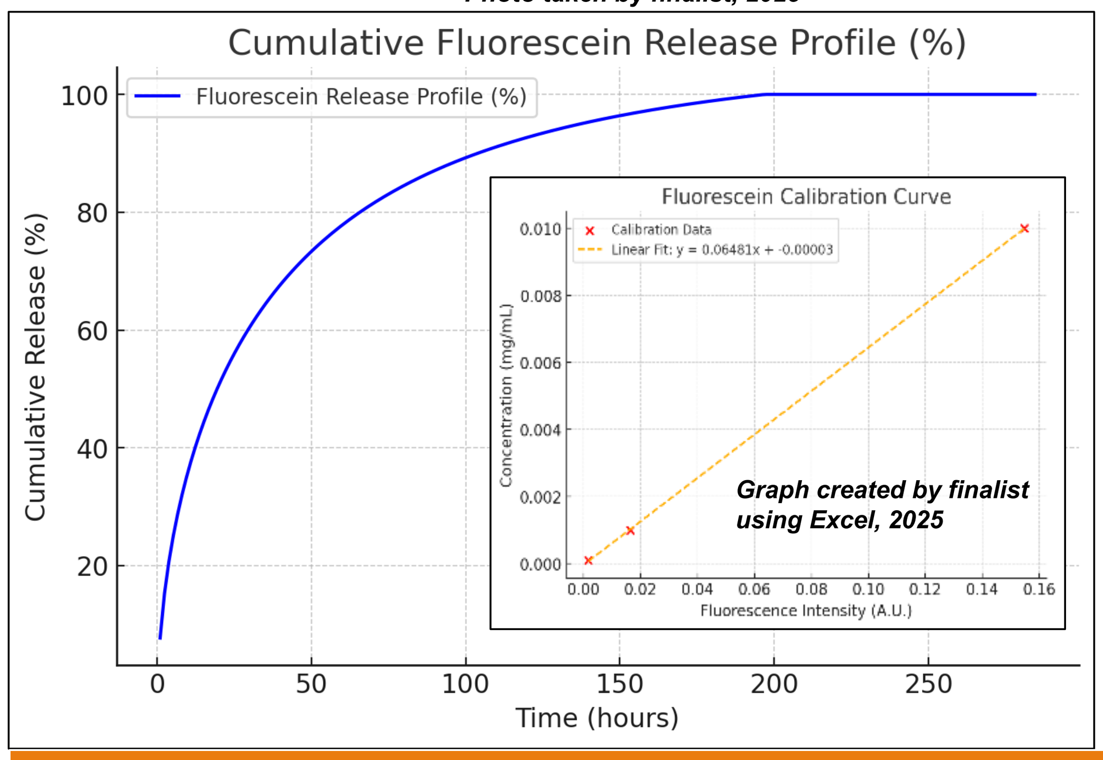


Photo taken by finalist, 2025

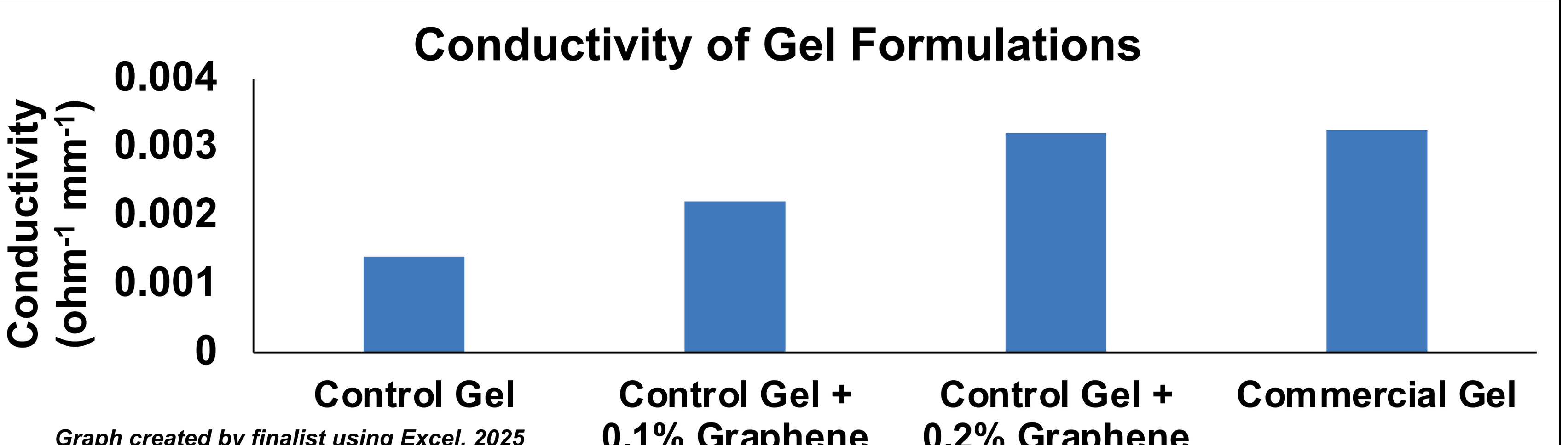
Photo taken by finalist, 2025



- **Gel exhibits a second phase of steady diffusion through the alginate-NIPAM hydrogel network**
- **Smart gel porosity can be tailored further to achieve desired drug delivery / controlled release properties**

Graph created by finalist using Excel, 2025

Application 3: Conductivity



Graph created by finalist using Excel, 2025

Materials	Electrode Impedance
Control Gel	6-8 k Ω
Control Gel + 0.1% Graphene	<5 k Ω
Control Gel + 0.2% Graphene	<5 k Ω
Commercial Gel	<5 k Ω

Table created by finalist using Powerpoint, 2025

- Smart gel polymer content was mixed with varying levels of conductive rotated graphene using a homogenizer and formulations were tested in an impedance measurement device
- **Gels exhibited relatively low impedance and high signal to noise ratio**

Application 4: Thermal Mgmt.

Heat sinks are used to dissipate heat, as increased temperatures can decrease the life expectancy and sensitivity of electronics. Devices also use fans for cooling, but **the phase change gel efficiently dissipates heat at low cost.**

Image taken by finalist, 2025

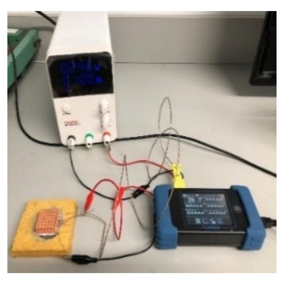
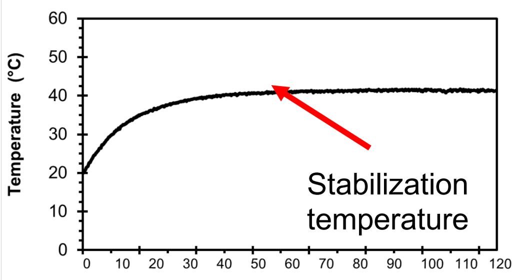


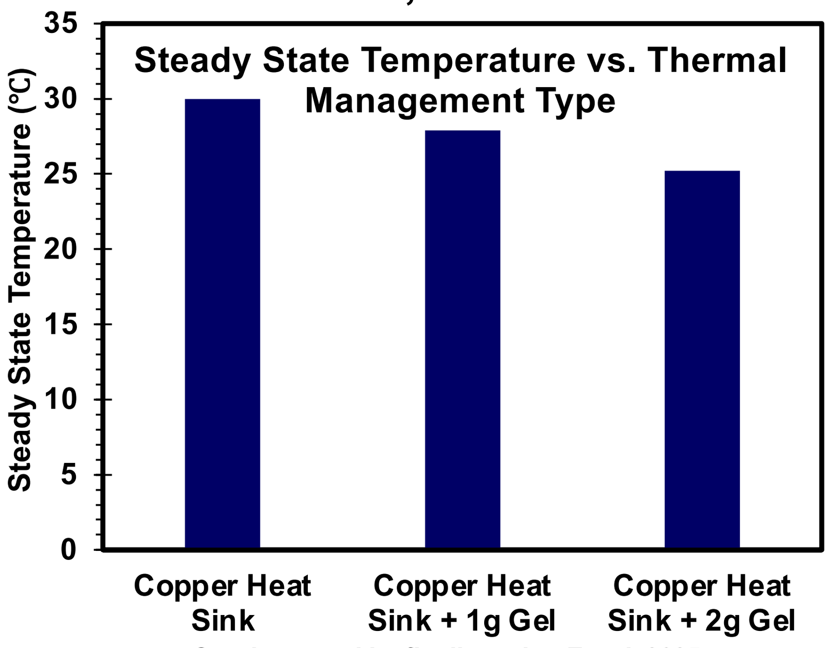
Image taken by finalist, 2025



Graph created by finalist using Excel, 2025

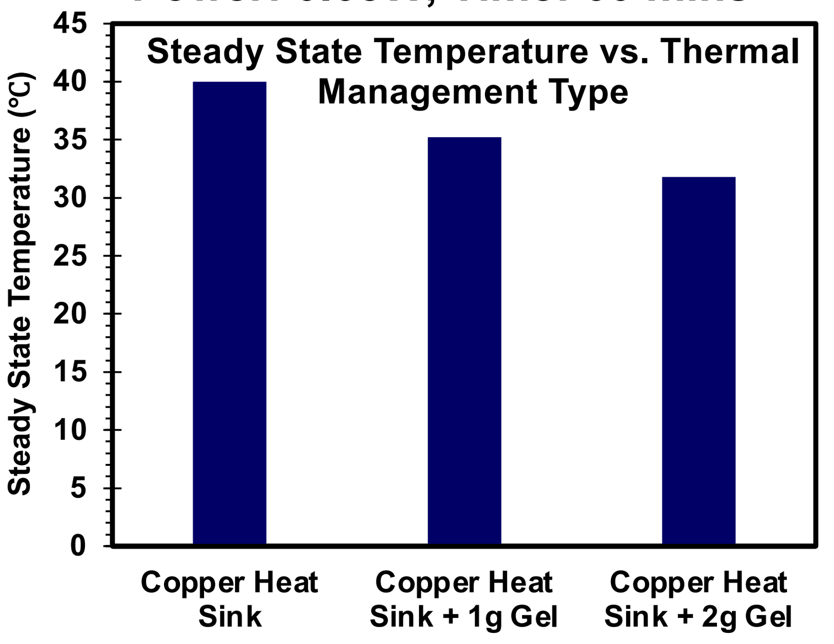
Representative temperature curve result

Power: 0.3W, Time: 60 mins



Graph created by finalist using Excel, 2025

Power: 0.65W, Time: 60 mins



Graph created by finalist using Excel, 2025

In both experiments, the smart gel was able to sufficiently dissipate heat and cool the metal block.

Conclusions

- Smart gel formulations were developed using alginate/NIPAM and optimized for 3D printing using low-cost printers.
- Thermo-responsive behavior of the gel around 37°C
- Demonstrated the smart gels in various applications using the following properties - thermal responsiveness, conductivity, and stability/porosity.

References

1. Ouyang, L. "Pushing the rheological and mechanical boundaries of extrusion-based 3D bioprinting." Trends in biotechnology 40.7 (2022): 891-902.
2. Li, Y., Zheng, W., Zhang, J., Xu, L., Li, B., Dong, J., Gao, G.-L., & Jiang, Z. (2023). 3D printed thermo-responsive electroconductive hydrogel and its application for motion sensor. Frontiers in Materials, 10, 1096475. https://doi.org/10.3389/fmats.2023.1096475
3. Atoufi, Z., Zarrintaj, P., Motlagh, G. H., Amiri, A., Bagher, Z., & Kamrava, S. K. (2017). A novel bio electro active alginate-aniline tetramer/ agarose scaffold for tissue engineering: synthesis, characterization, drug release and cell culture study. Journal of Biomaterials Science, Polymer Edition, 28(15), 1617–1638. https://doi.org/10.1080/09205063.2017.1340044
4. Zarrintaj, P., Jouyandeh, M., Ganjali, M. R., Hadavand, B. S., Mozafari, M., Sheiko, S. S., Vatankhah-Varnoosfaderani, M., Gutiérrez, T. J., & Saeb, M. R. (2019). Thermo-sensitive polymers in medicine: A review. European Polymer Journal, 117, 402–423. https://doi.org/10.1016/j.eurpolymj.2019.05.024

Ramesh, V.