

Executive Summary

Polymelt Solutions is developing a dual feeder prototype, designed to support the research & development of nanomaterials to reduce plastic waste. Our first-generation prototype will be fully integrated to a micro compounder, where its subsystems dispense liquid-graphene solutions and polymer pellets into separate inlets of the dual feeder.

Automating the system with the addition of a touchscreen interface ensures precise & controlled feed rates during experiments, while eliminating the risk of damaging equipment as seen on Figure 3.

Key challenges faced by the team include heat transfer analysis, tight tolerances, liquid evaporation, and manufacturing constraints. Nanomaterial science is a new and emerging field with limited research available, adding to the complexity of our deliverables.

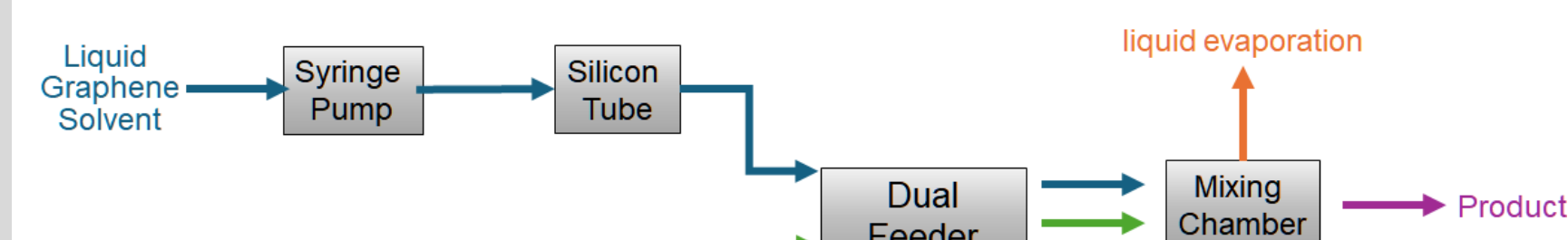


Figure 1. Dual Feeder Flow Diagram

Background

Micro compounders melt and process polymer granules at high temperatures and pressures to be extruded as continuous fibers for 3D printing and to test the formulations of new materials.

Researchers are interested in the addition of nanofillers during the melt phase of plastic pellets to improve the polymer's overall mechanical and electrical properties. The graphene is suspended in a liquid carrier, such as ethylene glycol (EG), to ensure uniform dispersion of the material inside the compounder.

The current approach is via manual injection of a liquid-graphene solution with a syringe, resulting in damage to the compounder's twin screws.

Ultimately, BNL hopes to transform single-use water bottles into restored polymers that can be used as 3D printing filament.

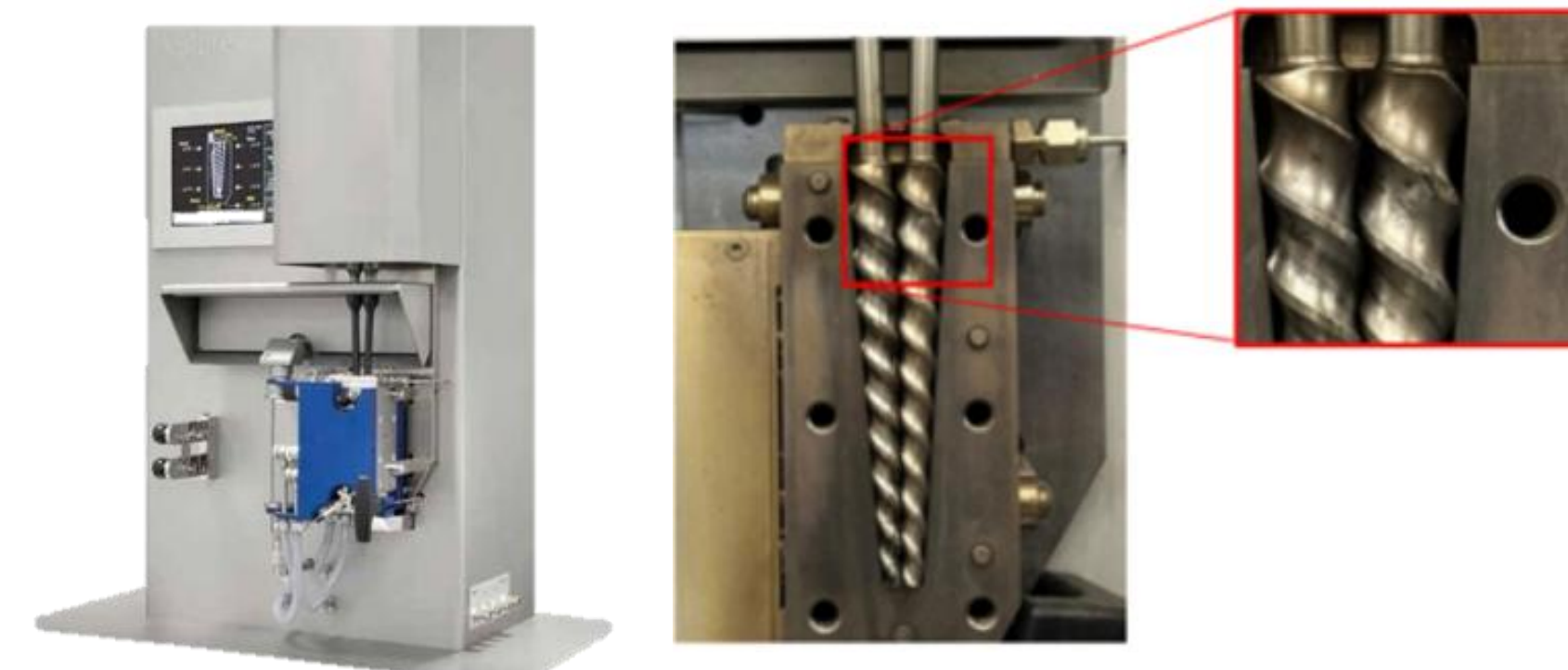


Figure 2. Xplore MC 5 Micro Compounder

Figure 3. Twin Screw Damage

Design Specifications

Geometric Constraints:

- Adapter must not exceed 9.8 mm OD
- Maximum compounder volume: 5 cm³

Temperature Constraints:

- Compounder operates at up to 400°C
- Heat transfer to dual feeder should not exceed 160°C to ensure safe handling and prevent premature evaporation of the liquid

Type of material:

- Components in contact with liquid or pellets must be constructed from corrosion-resistant, laboratory-grade materials that allow smooth flow and prevent cross-contamination.

Flow rate:

- Liquid flow rate: 1-10 mL/min
- Pellet flow rate: Pellet flow rate depends on the type of polymer and its melt rate.
- Dispensing systems must maintain accurate and repeatable flow rates.

Design Approach



Figure 4. Design Approach

Pellet Dispenser:

Goal - Designed to reliably dispense the polymer pellets into the dual feeder without jamming

Mechanism - Servo motor drives dispensing wheel to open & close

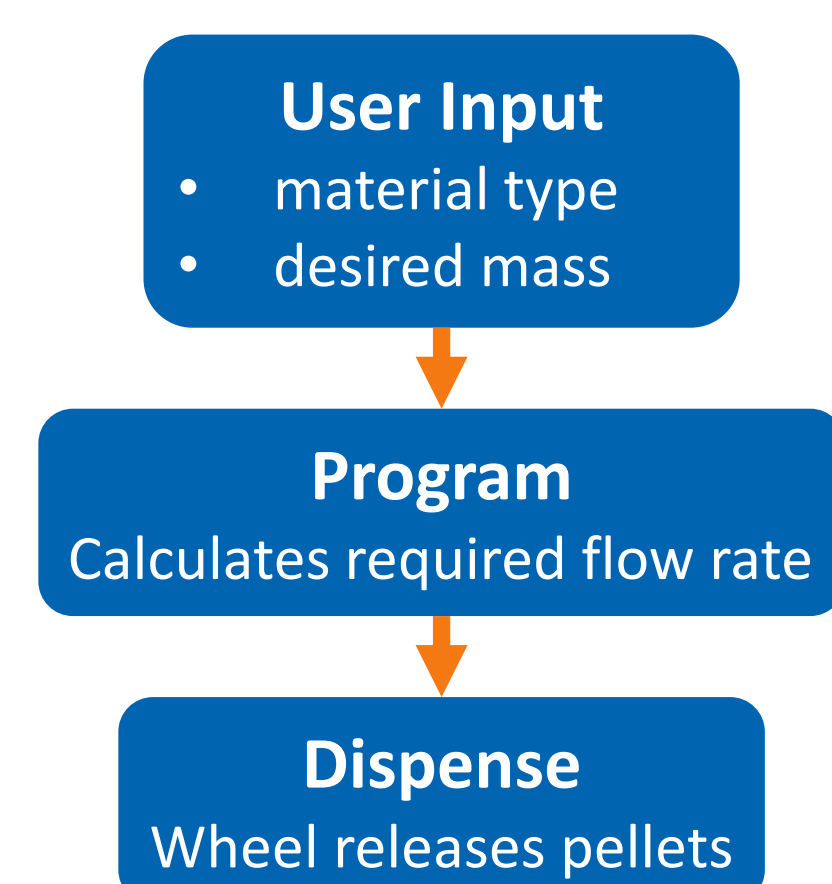


Figure 5. Pellet Flow Process

Syringe Pump:

Goal - Dispenses solution through a silicone tube into the compounder

Mechanism - Linearly displace syringe with a stepper motor connected to a ball screw shaft.

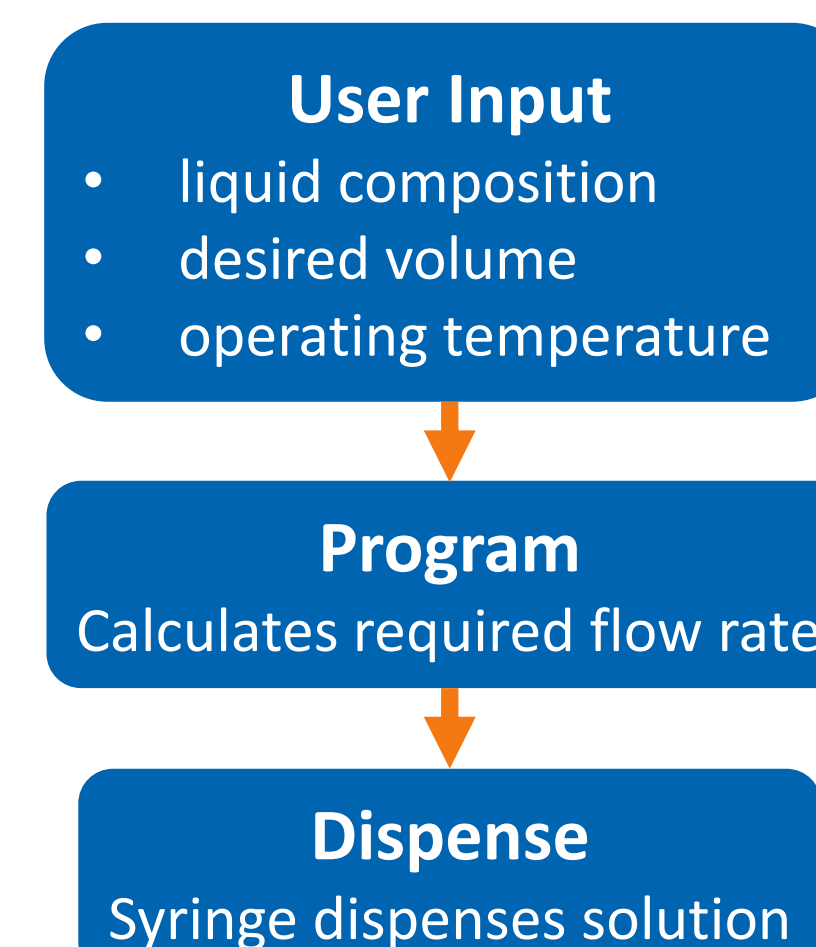


Figure 6. Liquid Flow Process

Dual Feeder:

- Designed to reliably dispense the polymer pellets into the dual feeder.
- Channel the filler solution from the syringe pump to the mixing chamber.
- Ensure the pellets and filler remain separate until they meet inside the mixing chamber.

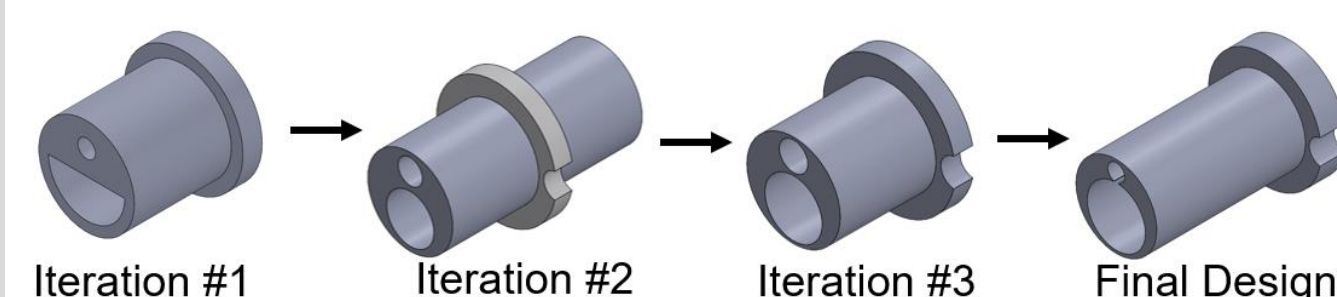


Figure 7. Adapter Design Iterations

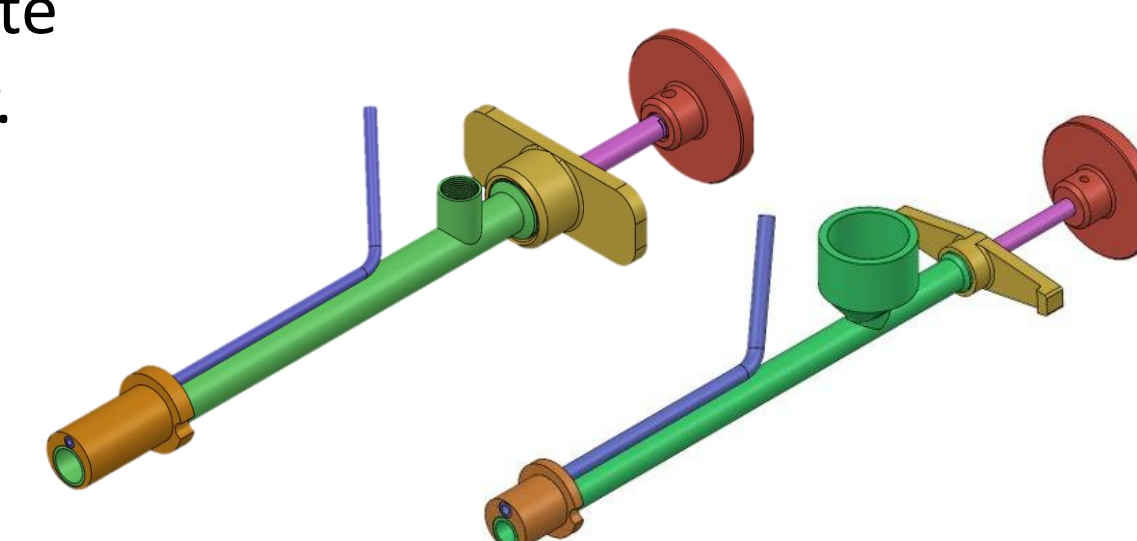


Figure 8. Dual Feeder Design Iterations

Material Selection

ANSYS Thermal Analysis Material Selection:

- Several materials were analyzed at 190°C
- 316 stainless steel selected for dual feeder material due to lowest heat transfer to lower evaporation rate

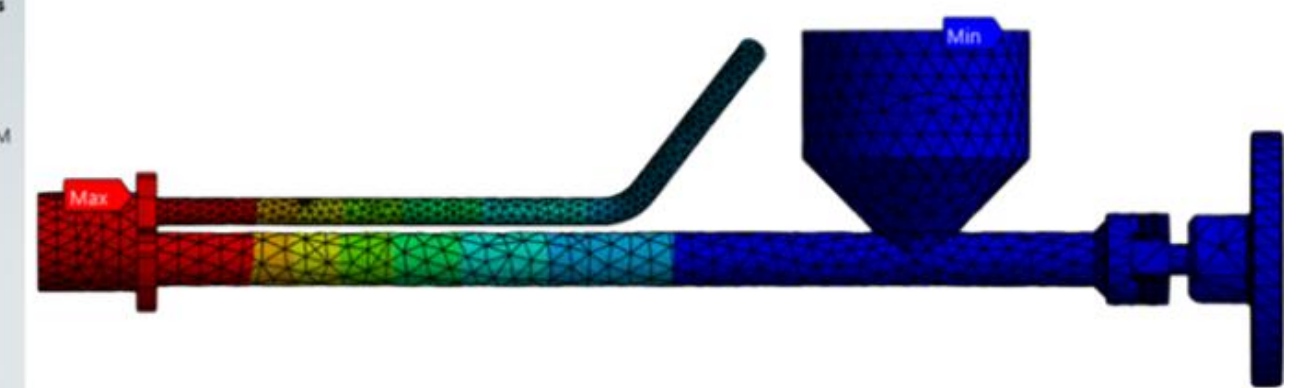
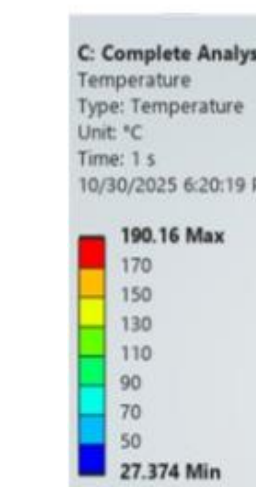


Figure 9. ANSYS Thermal Analysis

Experimental Results

Mass Flow Rate Experiment:

- Performed to program mass flow rate per cycle for pellet dispenser.
- Touchscreen will allow material and mass flow rate selection

Table 1. Mass Flow Rate Experiment

Material	PP	PBT	PET
Average Time (s)	1.08	1.24	1.33
Mass/Cycle (mg)	56.9	79.6	15.3
Flow Rate (mg/s)	52.7	62.4	11.5

Table 2. Liquid Evaporation Results

Liquid Solution	Average Evaporation Rate (mL/min)
Ethylene Glycol	0.2140
Graphene Solution (0.5% wt)	0.2776

Liquid Evaporation:

- The mass of the liquid solutions were weighed before and after entering an oven at 190°C at a fixed time
- Average evaporation rate is shown in Table 2

Conclusions

There is no such thing as a final design, there is only a design freeze. Ultimately, the team decided to design a dual feeder that would maximize the pellet's material flow rate while reducing the design's complexity to reduce manufacturing costs.

Adding automation to a system was not an easy feat. To program the pellet dispenser, multiple experiments to optimize material flow rate were done. To program the syringe pump, key criteria such as the micro compounder's evaporation rate & extrusion rate were analyzed. Finally, a touchscreen interface was designed, integrating all 3 systems with different feeding options at the client's request.

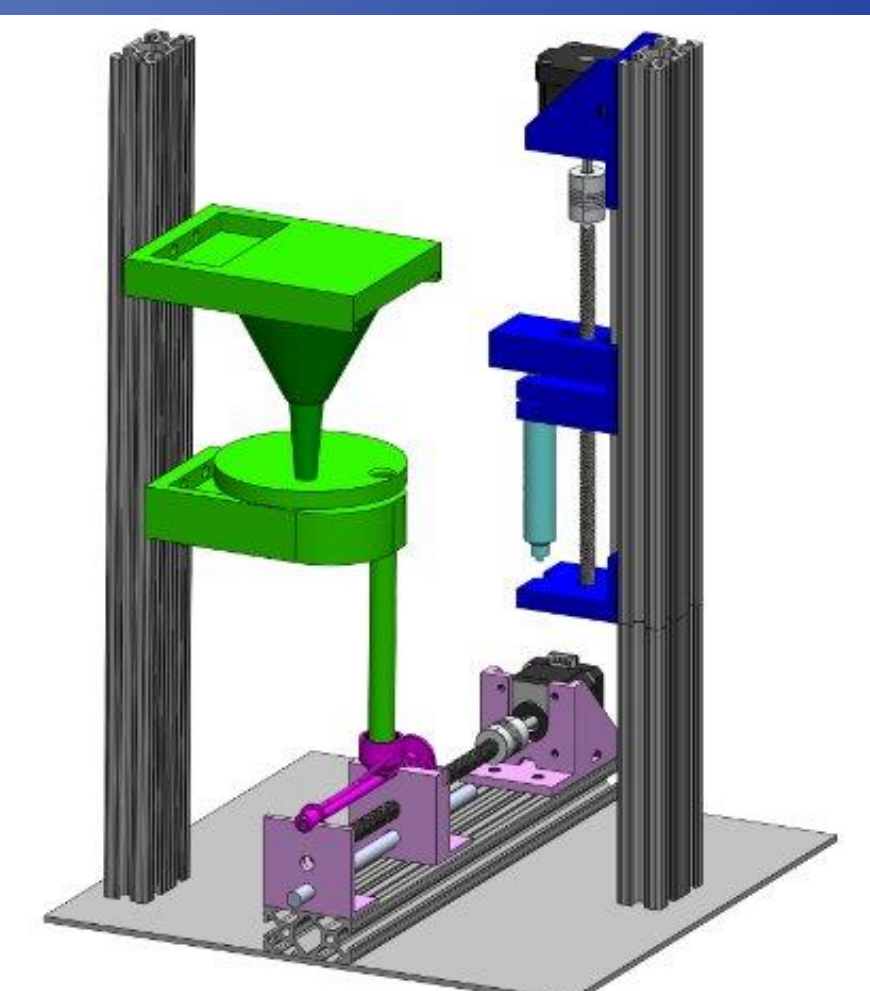
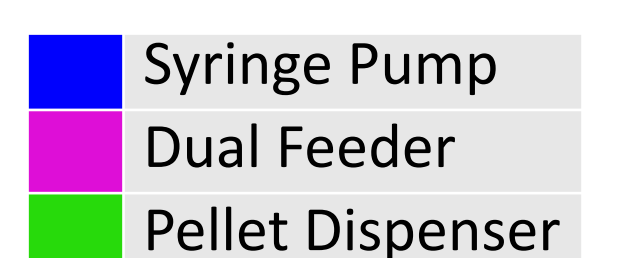


Figure 10. Final Prototype



References

1. Liu, S., and Bobrow, J. E., "An Analysis of a Pneumatic Servo System and Its Application to a Computer-Controlled Robot," ASME Journal of Dynamic Systems, Measurement, and Control, 1988, Vol 110 pp 228-235.
2. Dr. D. Flo. (2020, October 31). DIY syringe pump using 3D printed parts and stepper motor [Video]. YouTube. https://www.youtube.com/watch?v=UHa-OKb_CiM
3. Bergman, T.L., Lavine, A.S. (2017) Diffusion Mass Transfer. *Fundamentals of Heat and Mass Transfer* (pp. 849-887), John Wiley & Sons, Inc.