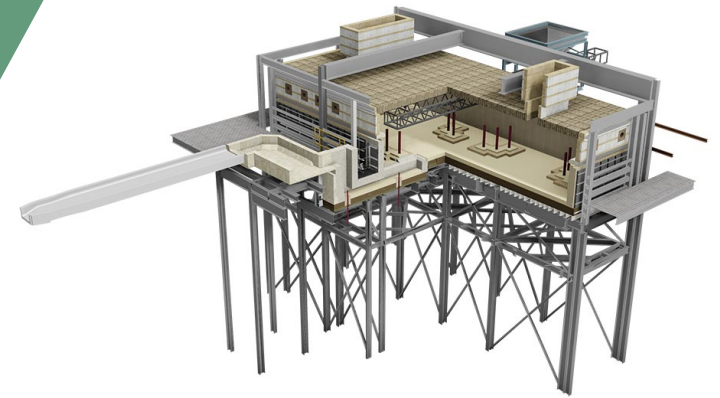


Cold-Top Batch Dynamics in All-Electric Melters

ERIC MUSKOVIN

9/15/2026



U.S. DEPARTMENT OF
ENERGY

GMIC
GLASS MANUFACTURING
INDUSTRY COUNCIL

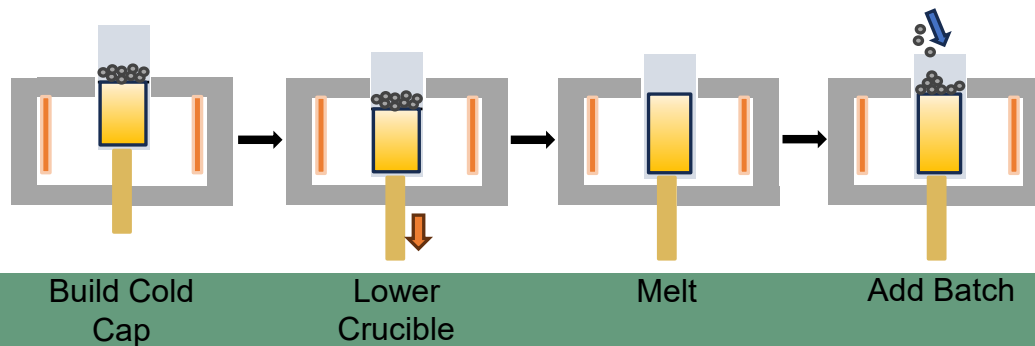
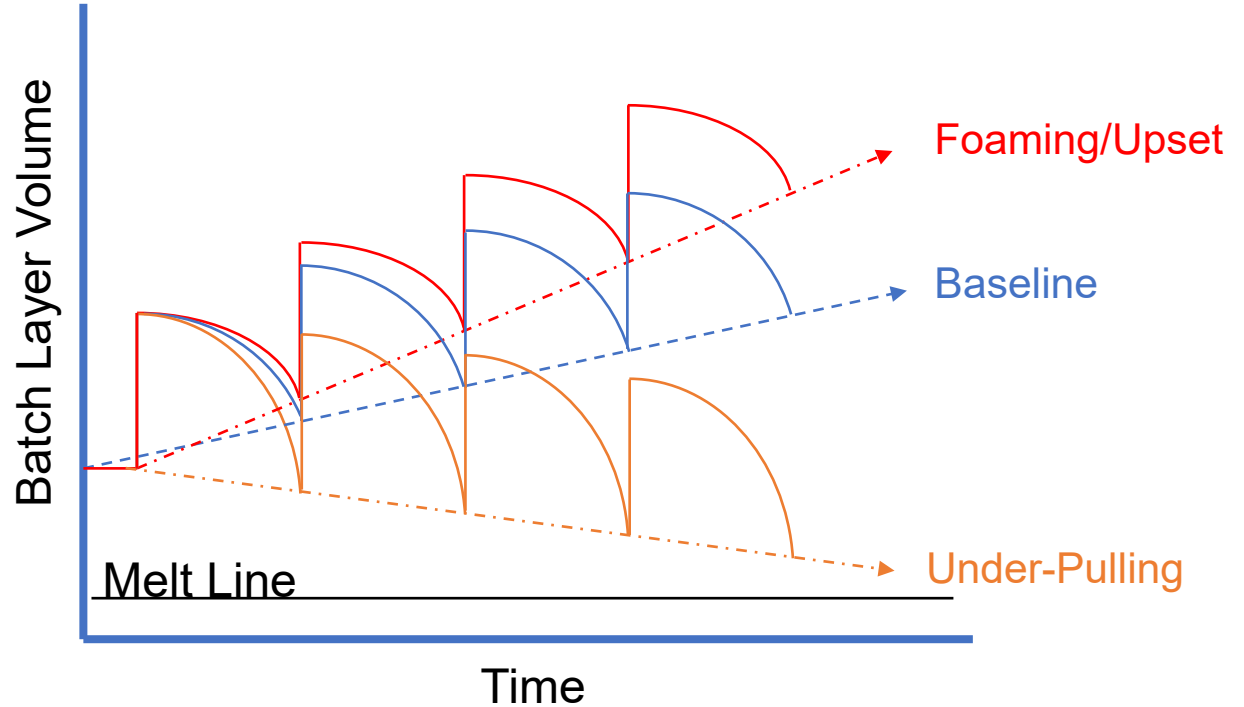
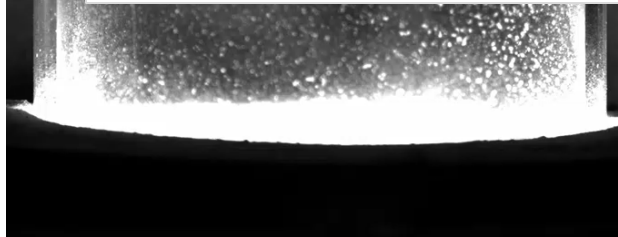
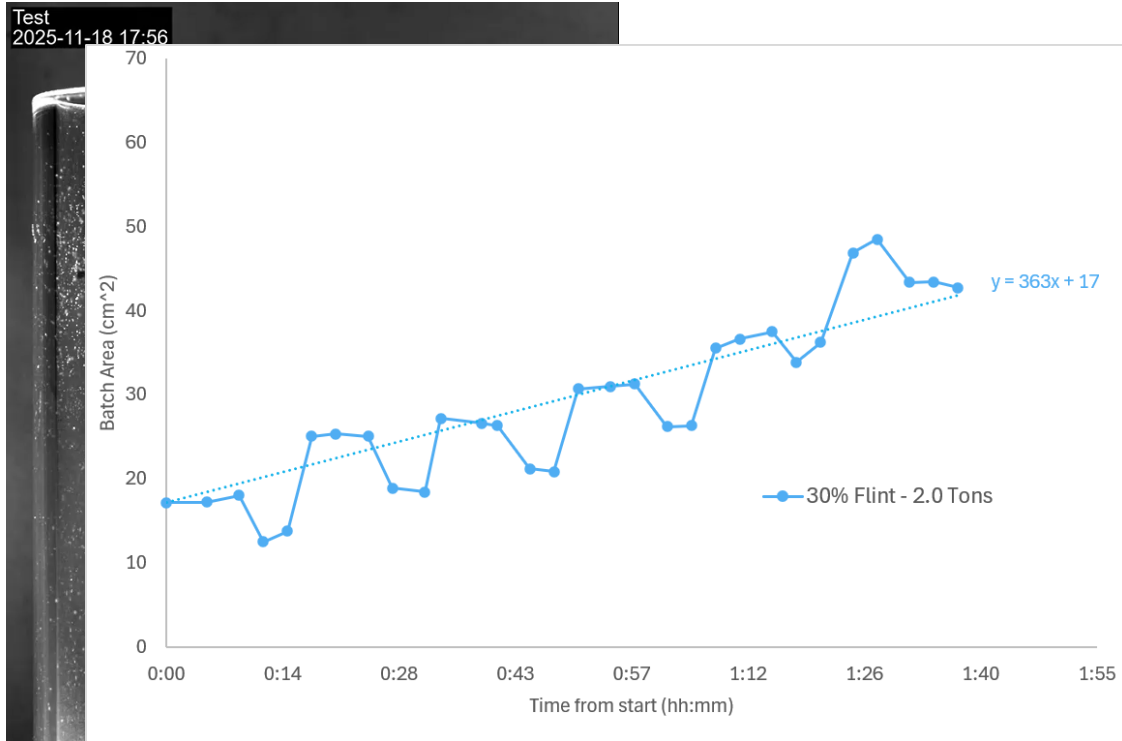

Pacific Northwest
NATIONAL LABORATORY

TECO
Toledo Engineering Co., Inc.

 **CelSian**

RoMan
MANUFACTURING

Comparable Metrics – Batch Layer Accumulation

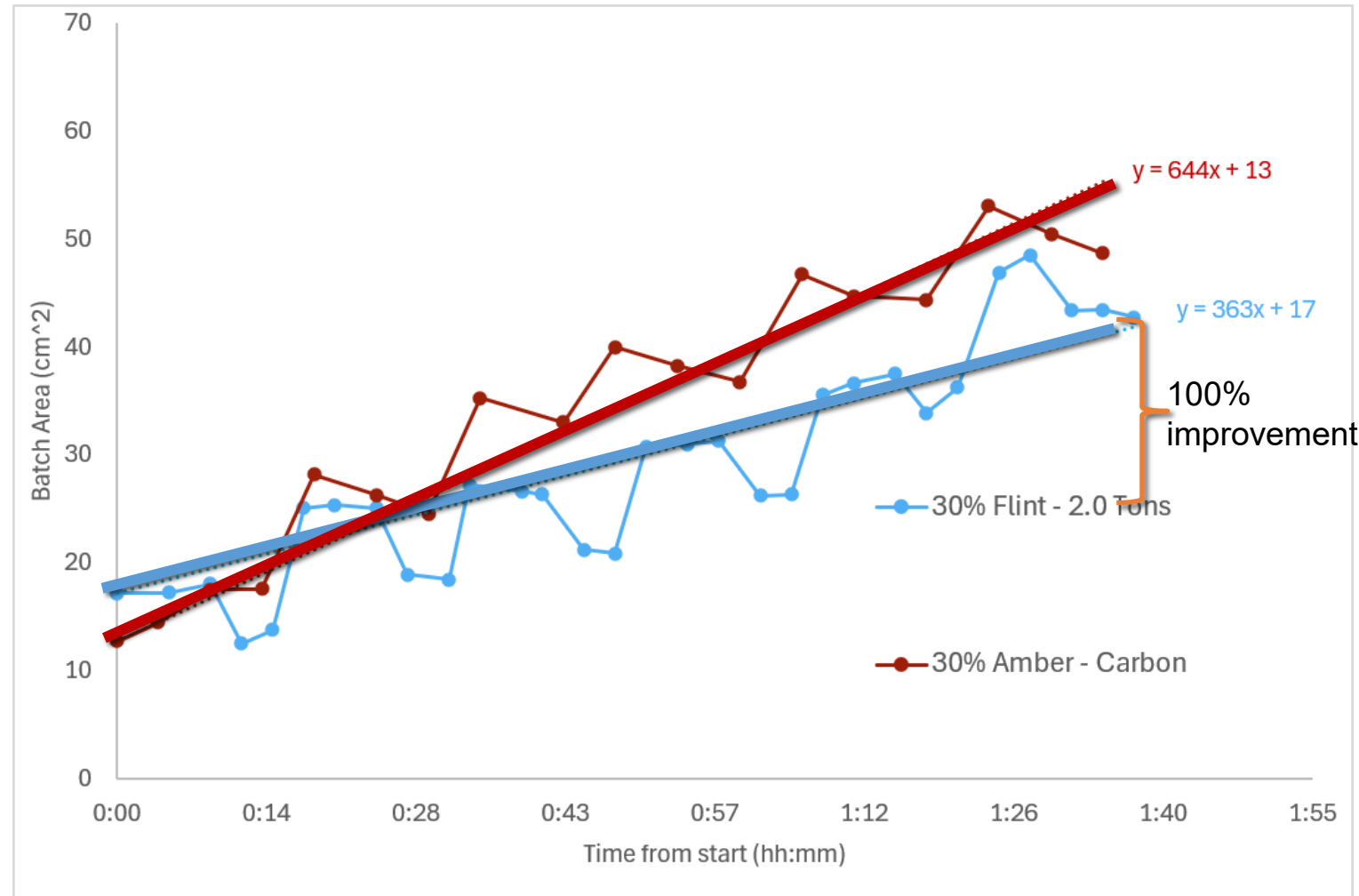


Standardization for Comparison – Batch Build-up Rate

- Two baselines for comparison:
 - Target = 30% Flint
 - Unfavorable = 30% Amber

$$\% \text{ improvement} = \frac{(\text{Ref. Amber} - \text{Variable})}{(\text{Ref. Amber} - \text{Ref. Flint})}$$

Flint containing 30% cullet is a favorable condition for production

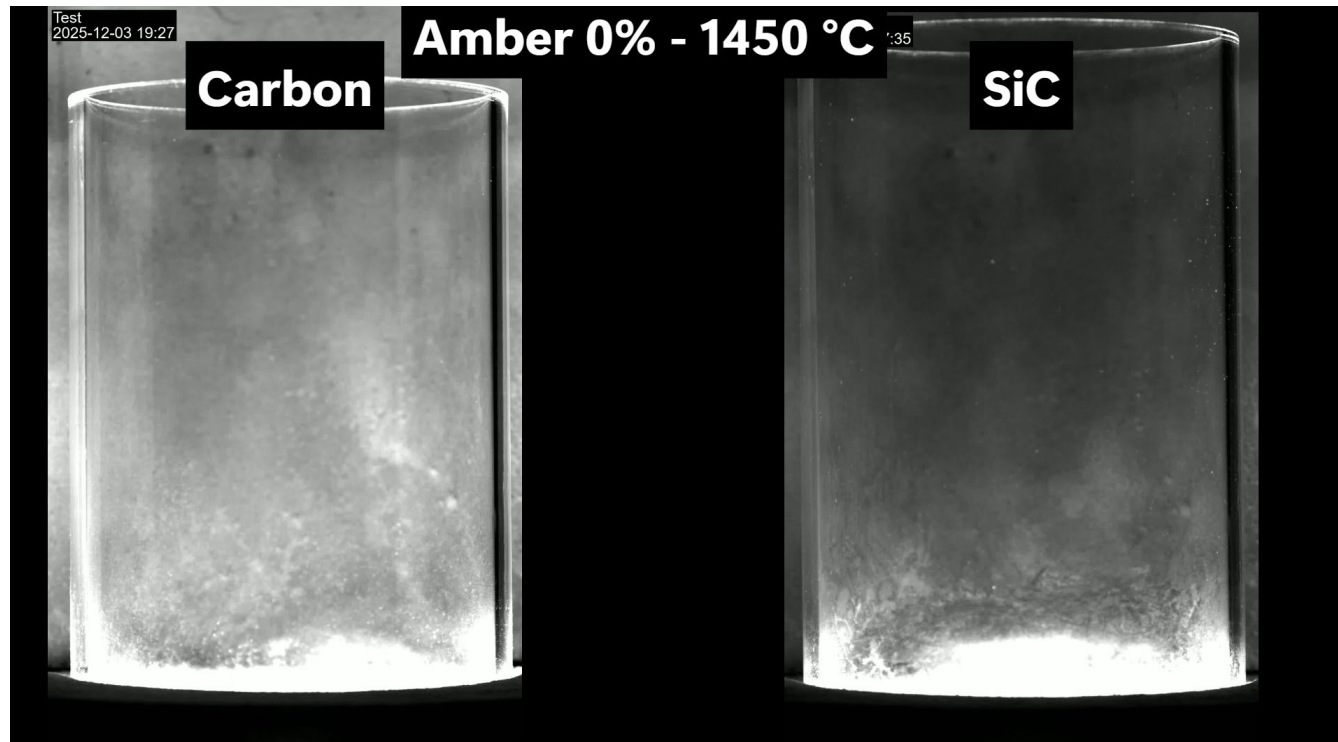




Alternative Reducing Agents

Mirroring PNNL Results (Amber - 0.45 wt% SiC)

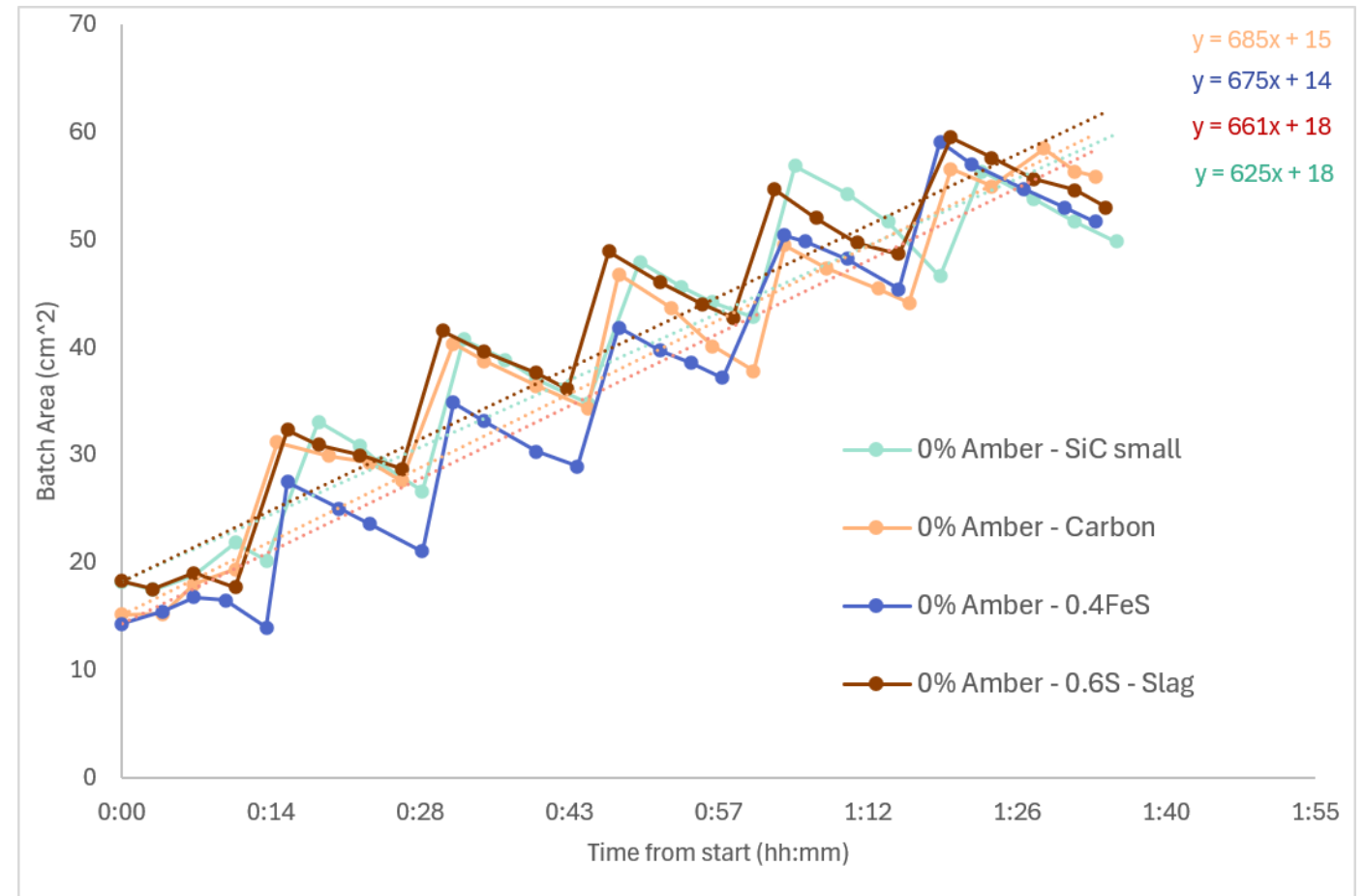
Same batch as PNNL FET test with best foaming reduction



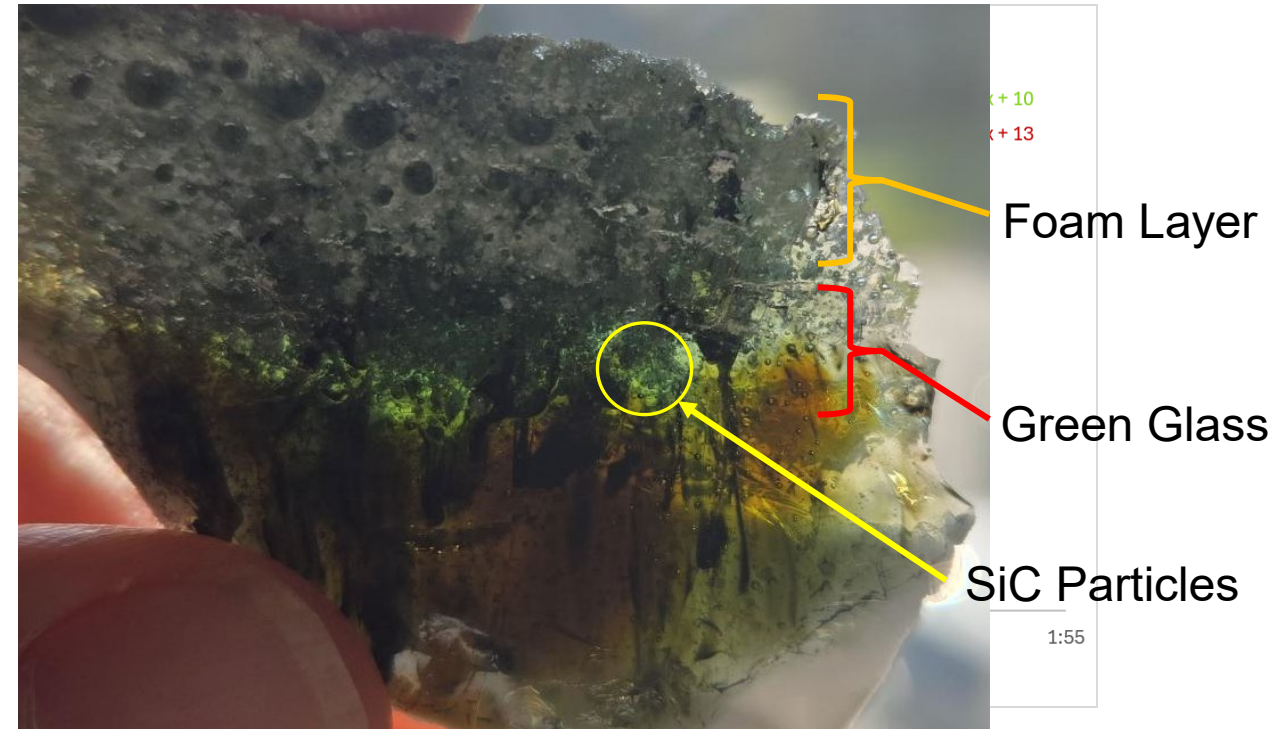
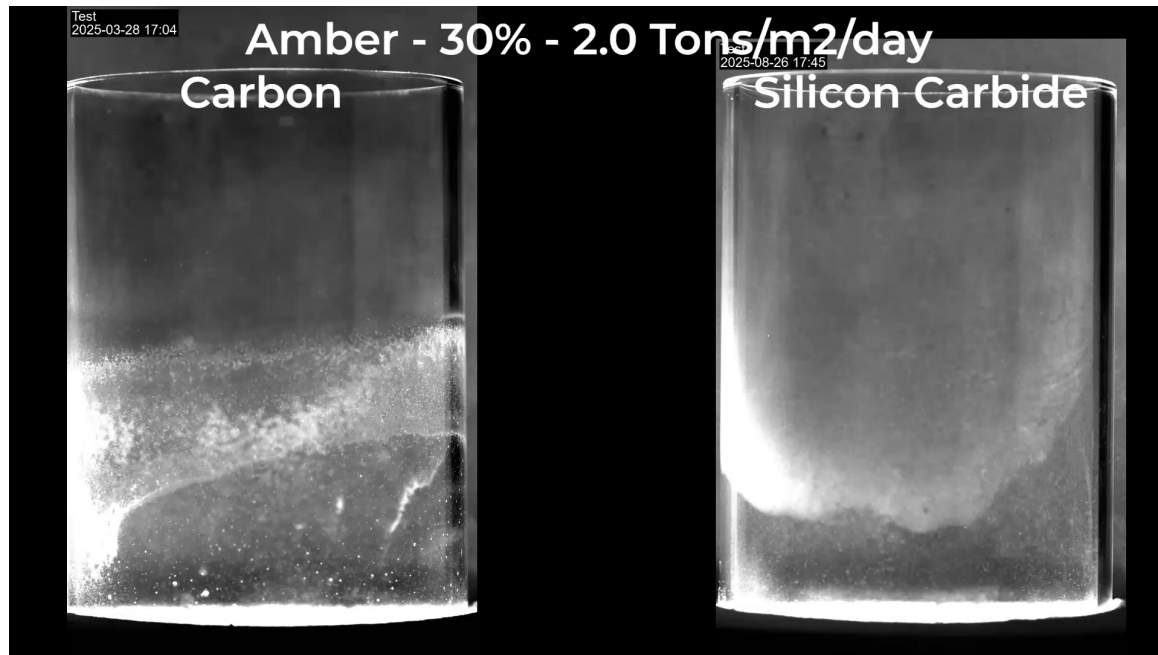
Visually, there are no significant differences between carbon and SiC ($\sim 1 \mu\text{m}$)

Alternative Amber Reducing Agents – 0% cullet

Coloring agent	Improvement
Iron Sulfide	2.5%
Blast Furnace Slag	6.2%
SiC (~1µm)	15.7%

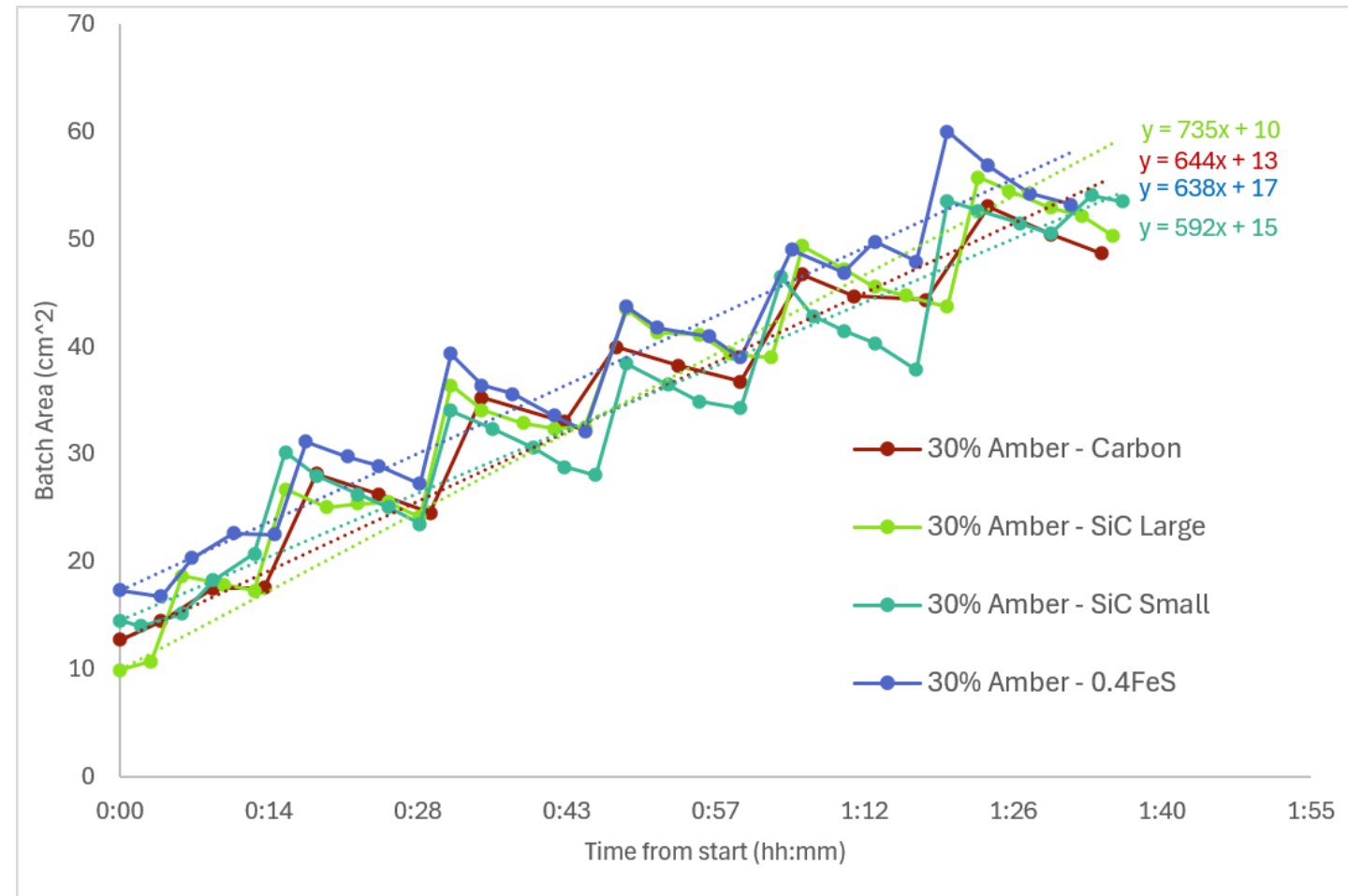


Amber with 30% Cullet & SiC (74 μ m)

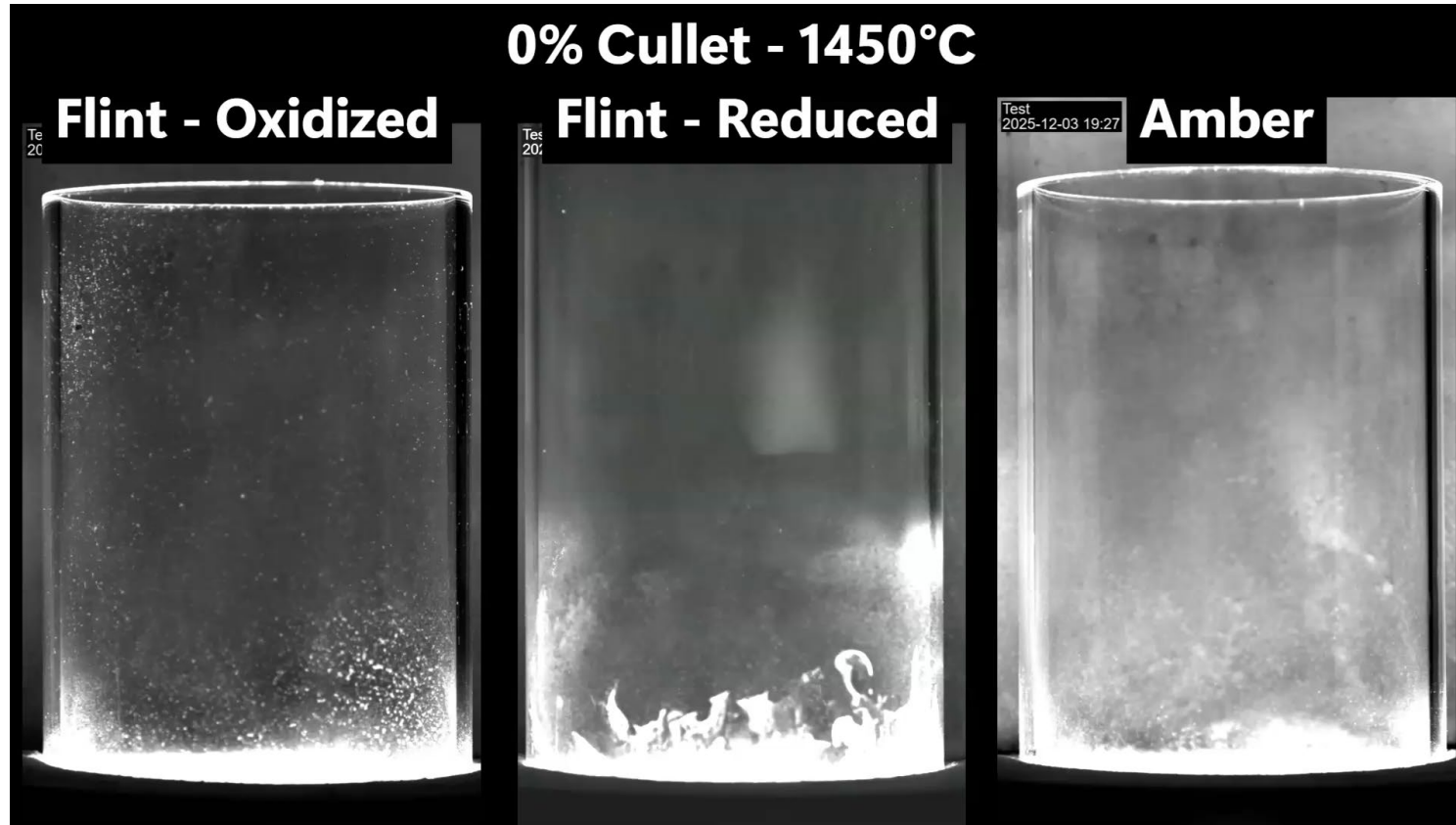


Alternative Amber Reducing Agents – 30% cullet

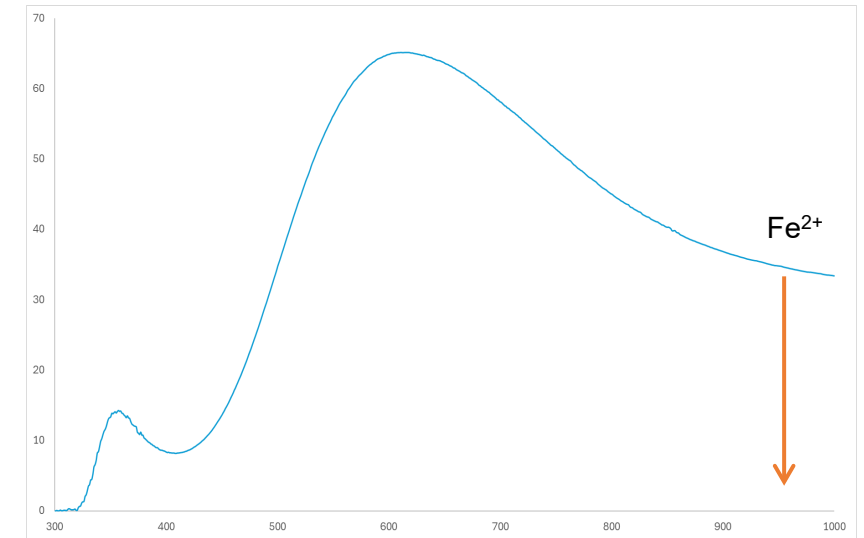
Coloring agent	Improvement
SiC (<74µm)	-24.5%
Iron Sulfide	1.6%
SiC (~1µm)	14.0%



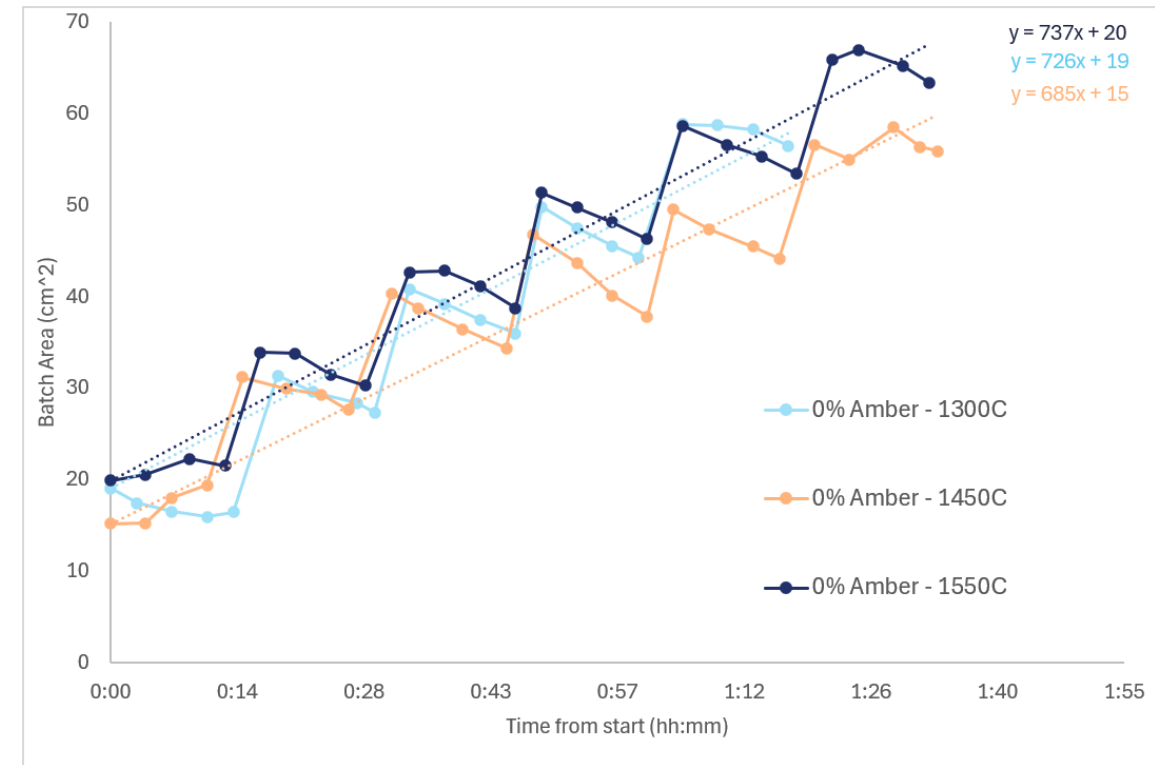
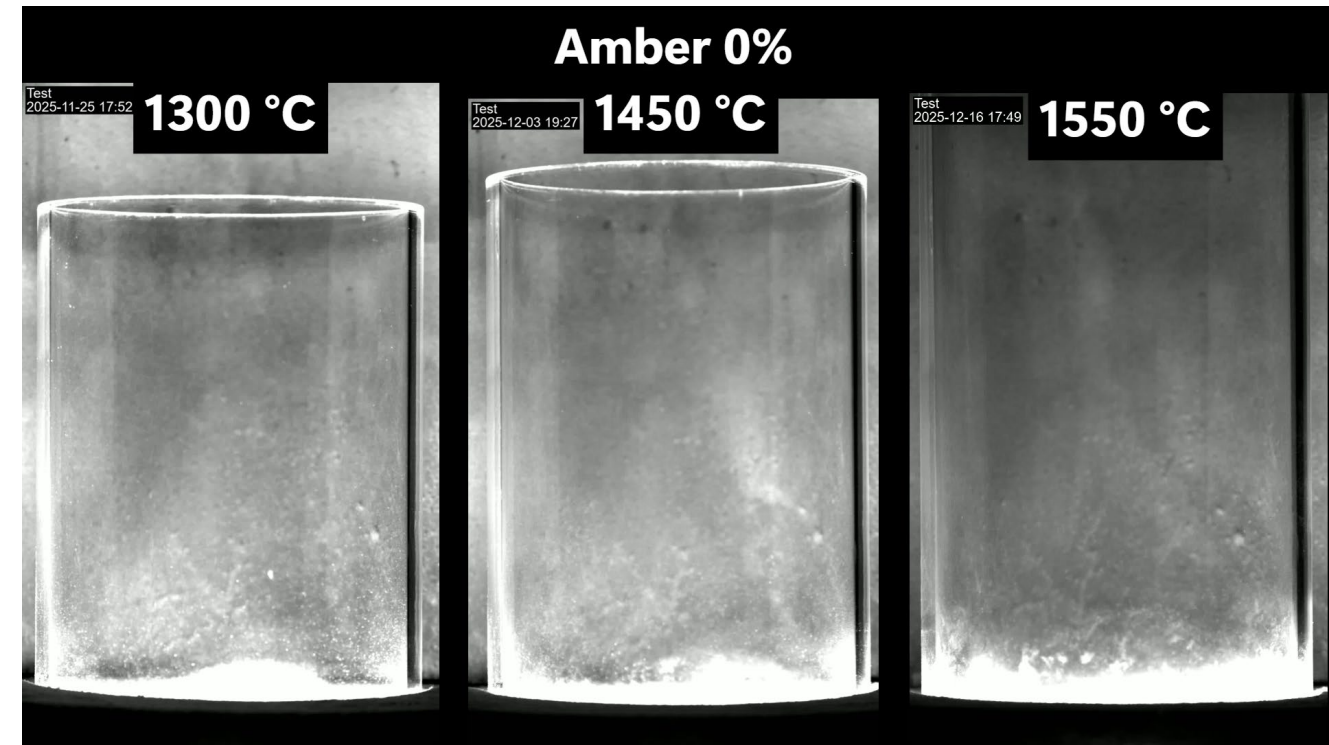
Problems with Heat Transfer – Reduced Flint



- Why so little change in Amber melts?
- Reduced Iron Flint (Amber without Sulfur added) behaved similarly to a standard amber melt
 - Foaming is still an issue, but lower heat transfer caused by Fe^{2+} is a major contributor

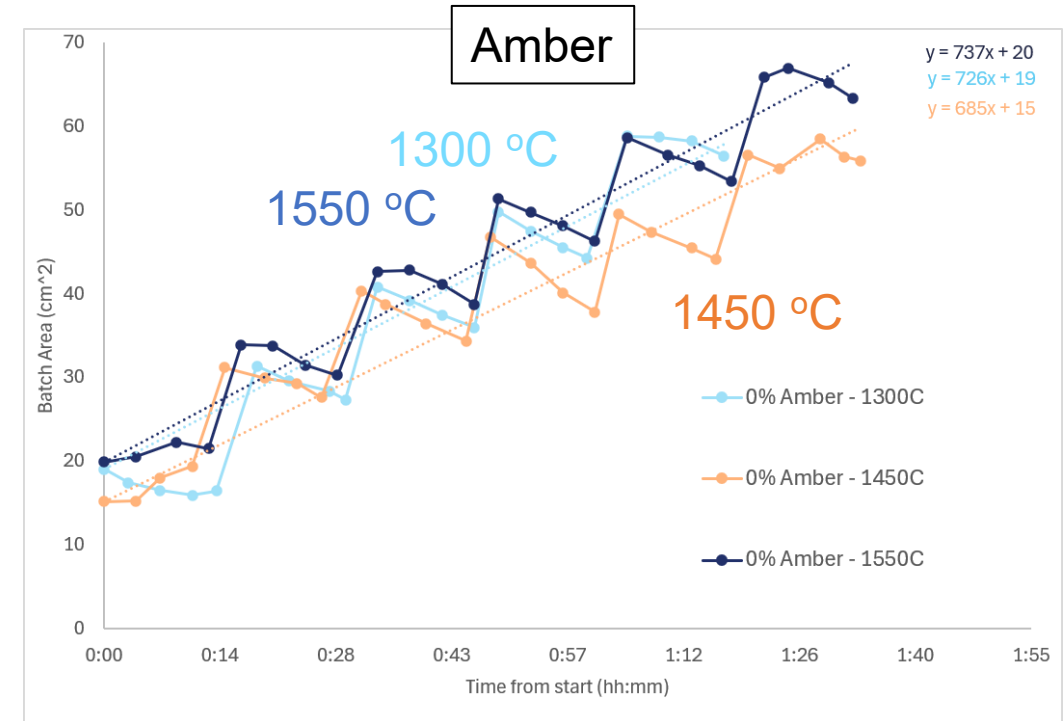
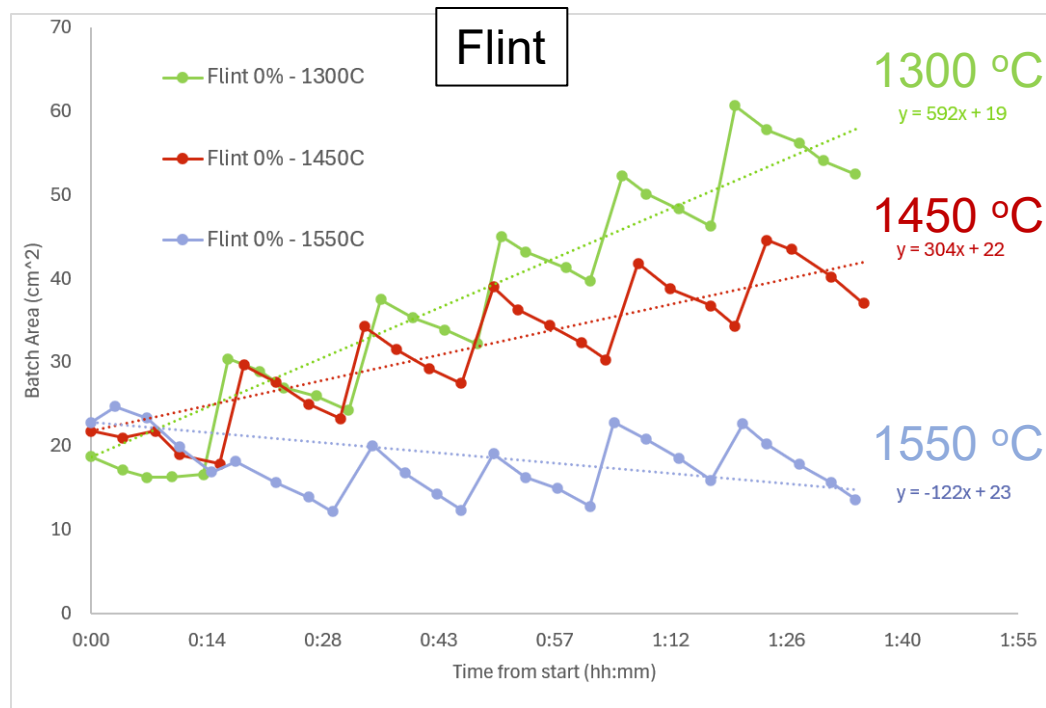


Amber – Melt Temperature Comparison



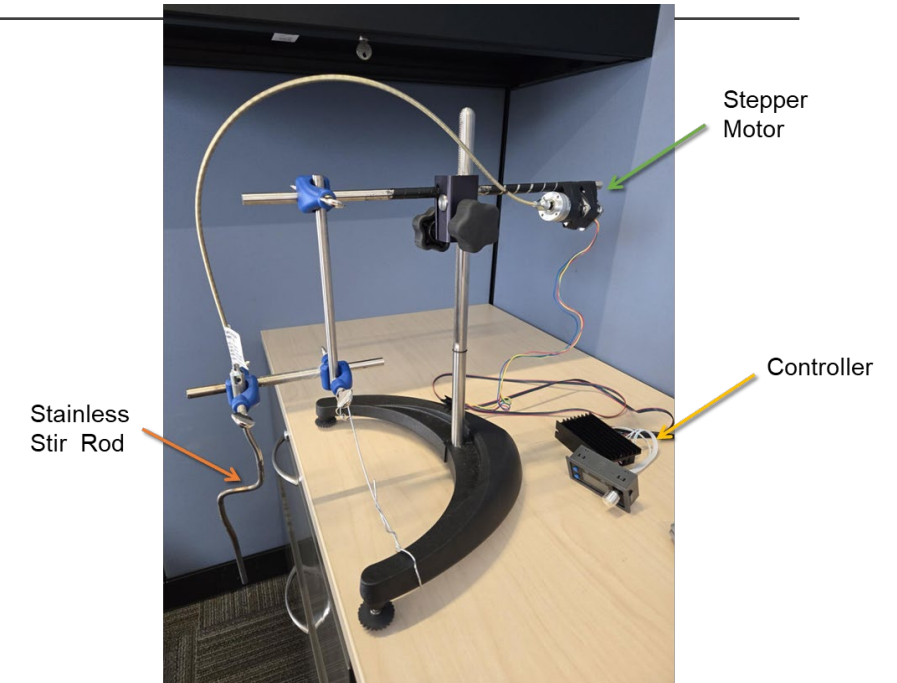
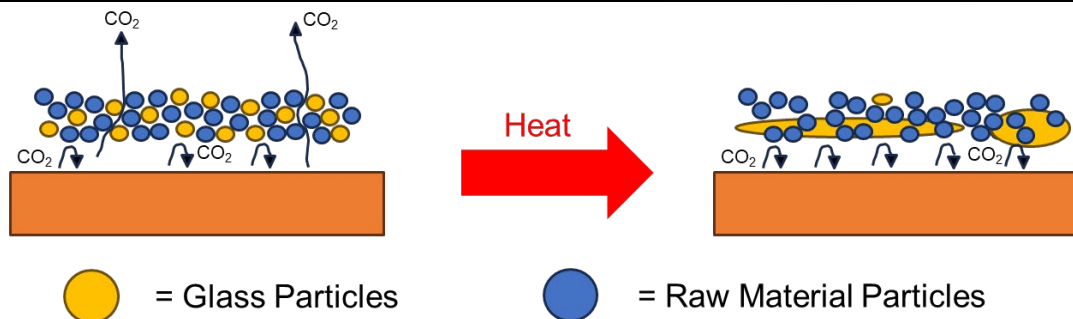
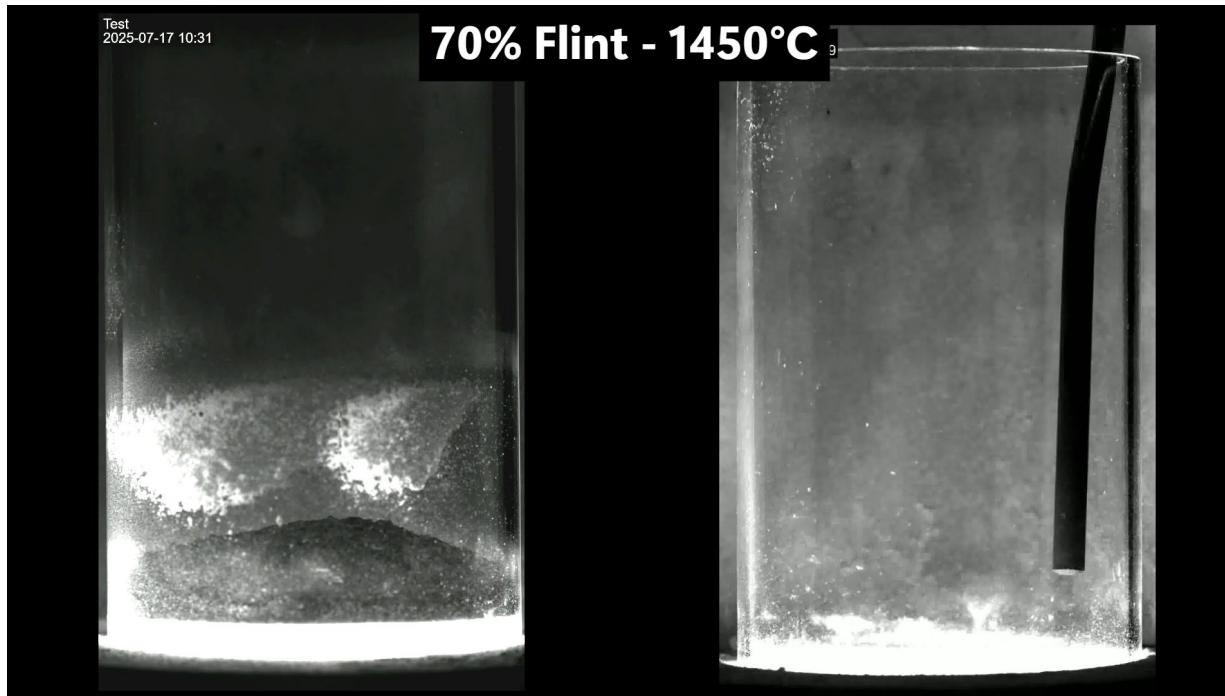
Temperature did not have the significant effect on the reduced amber melts

Melt Temperature Effect on Amber vs Flint



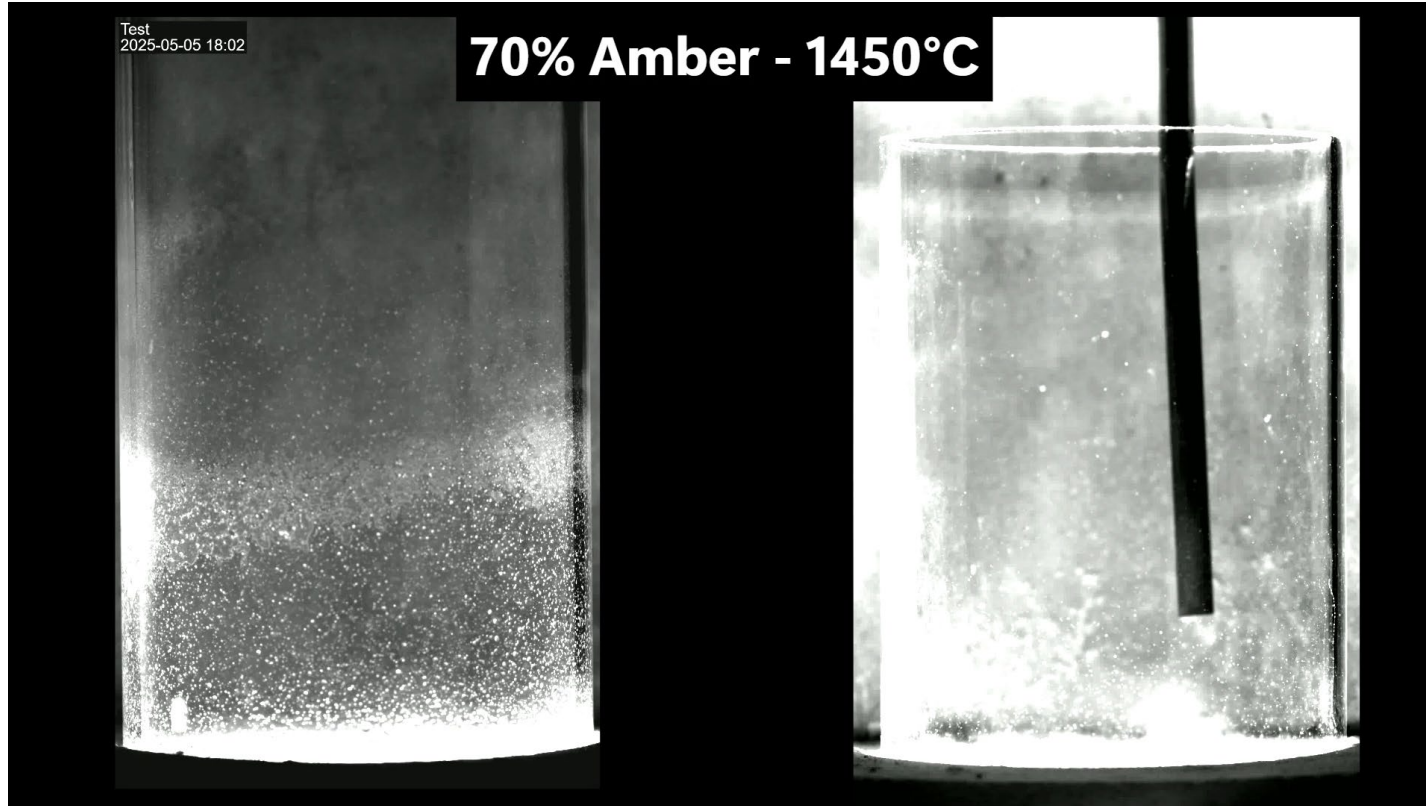
Gas Release by Agitation

Cold Cap Agitation – 70% Cullet Flint



- Flint batch with 70% cullet showed drastic improvement in melt rate
- Stir rod created more permeable batch layer for trapped gases to be released

Cold Cap Agitation – 70% Amber

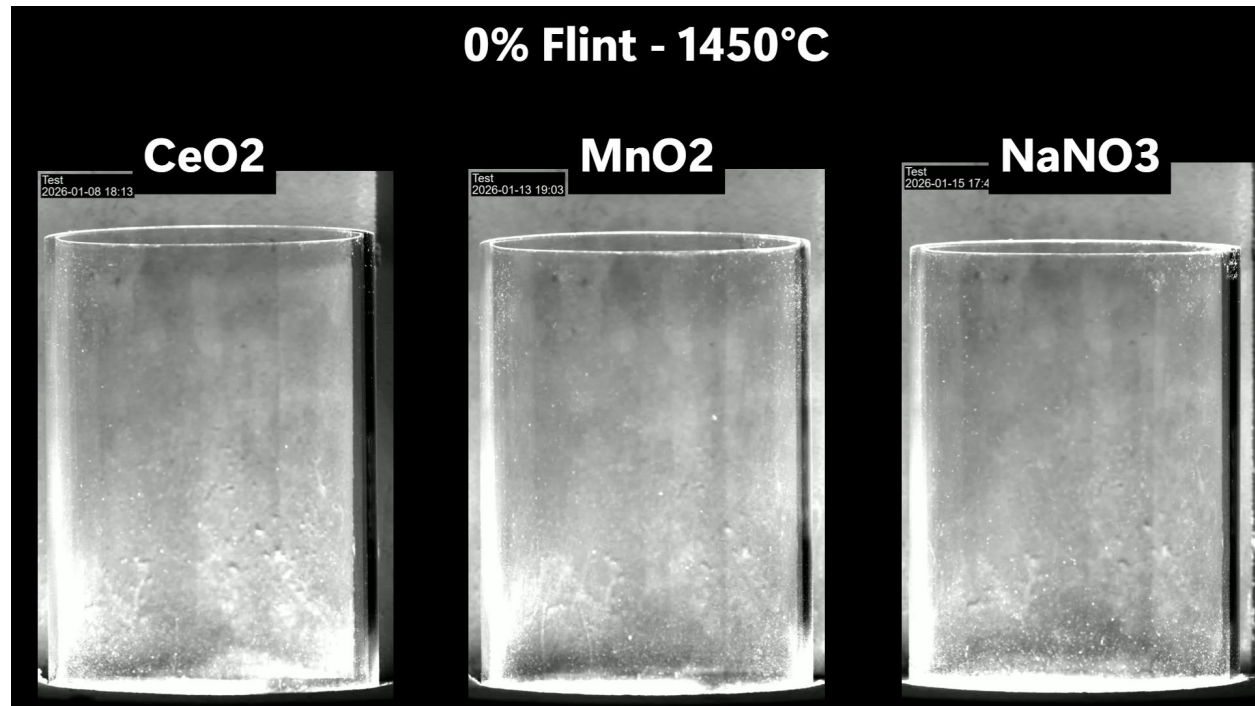


- Amber batch with 70% cullet was not successful
- Batch build-up was unchanged or slightly worse
- Stirrer required intervention multiple times from ceasing
- Cold bottom layer means more viscous melt

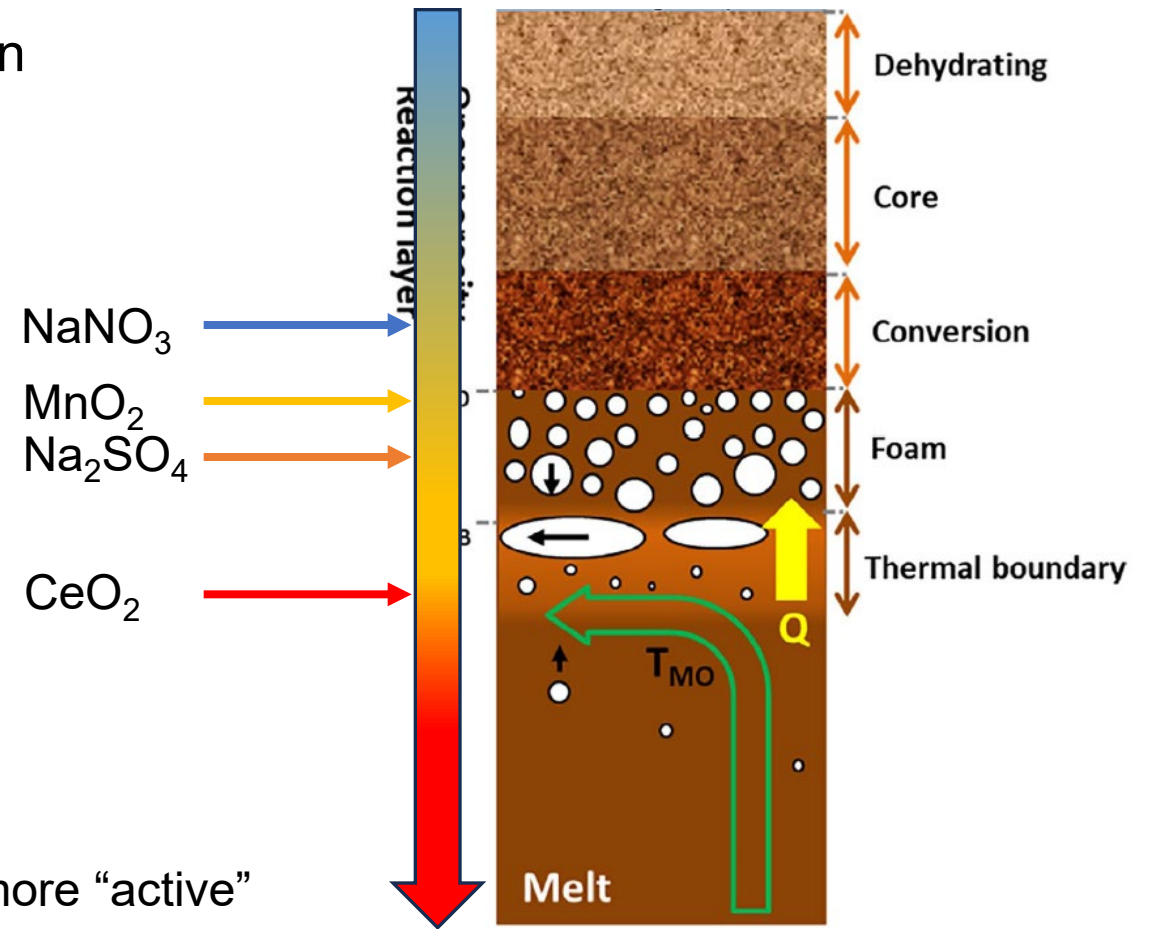
Effects of Oxidizers on Flint

Oxidizer Effects on Cold Cap

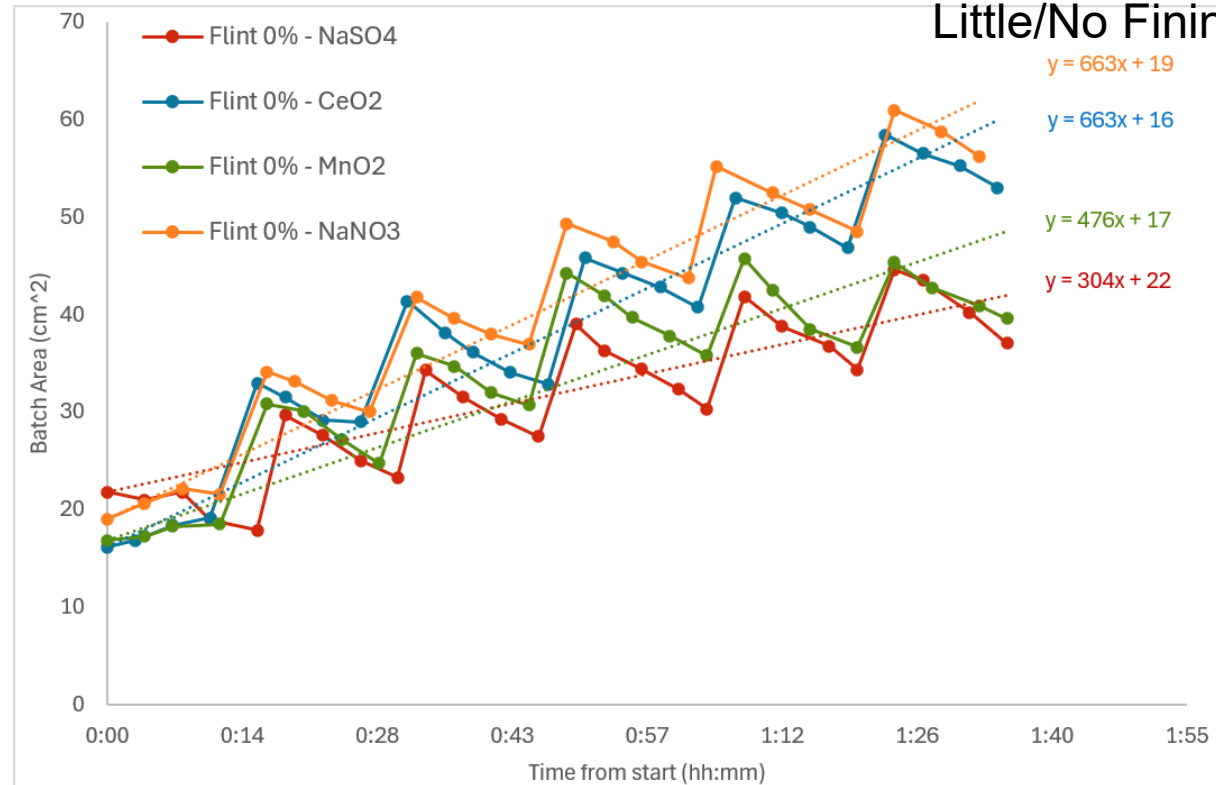
How does changing the thermal decomposition temperature change the cold-cap dynamics?



- CeO_2 and NaNO_3 had similar build-up rates; CeO_2 was more “active”
- MnO_2 had multiple batch collapses



Alternative Oxidizers – Glass Samples



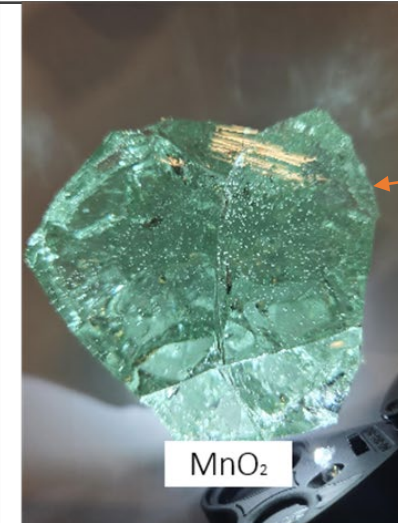
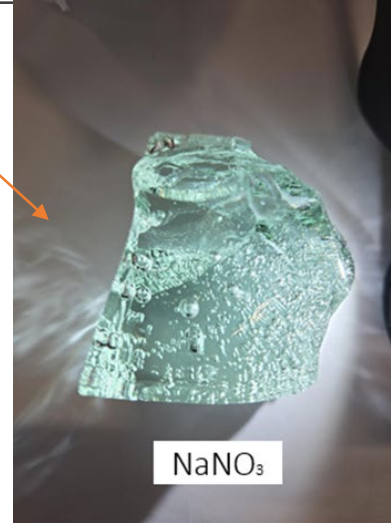
Little/No Fining

$$y = 663x + 19$$

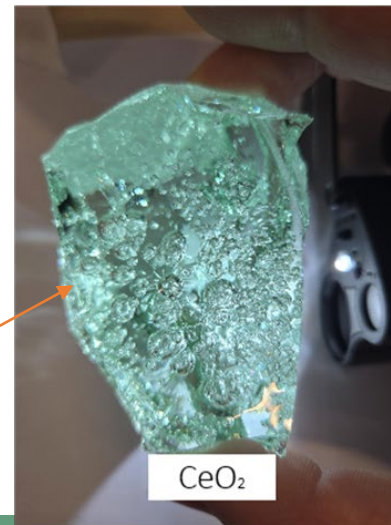
$$y = 663x + 16$$

$$y = 476x + 17$$

$$y = 304x + 22$$



Small Seeds
O₂ bubbles?



Best
fining/refining

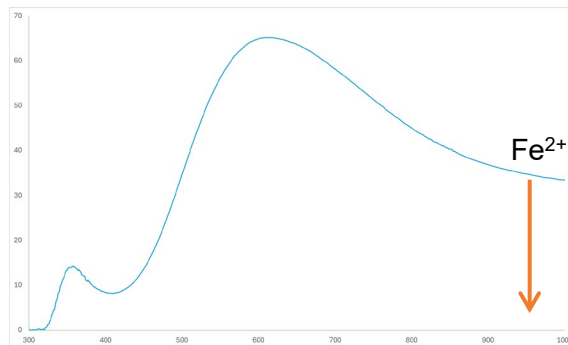
Large bubbles

Future Work

How do we get heat to the foam layer?

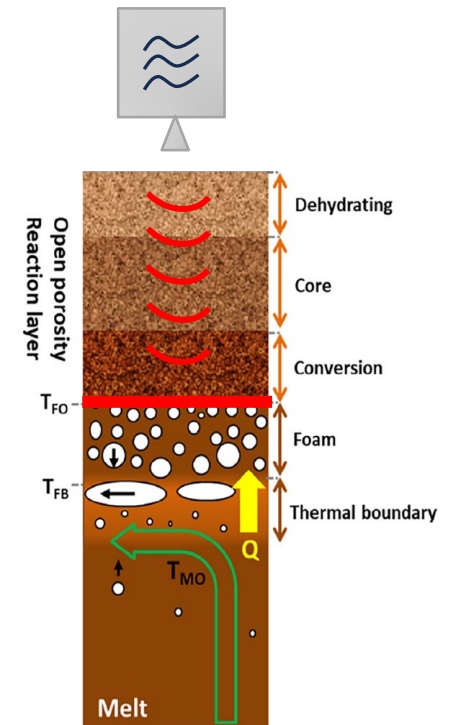
Oxidized Amber Composition

- Avoid redox mixing/sulfate release
- Reduce Fe^{2+} concentration to increase thermal conductivity of melt



Microwave/Induction Heating

- Direct radiative heating of the foam layer
- Super heat top layer of SO_2 foam to pop the bubbles



Thank you!

Questions?