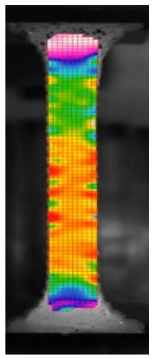
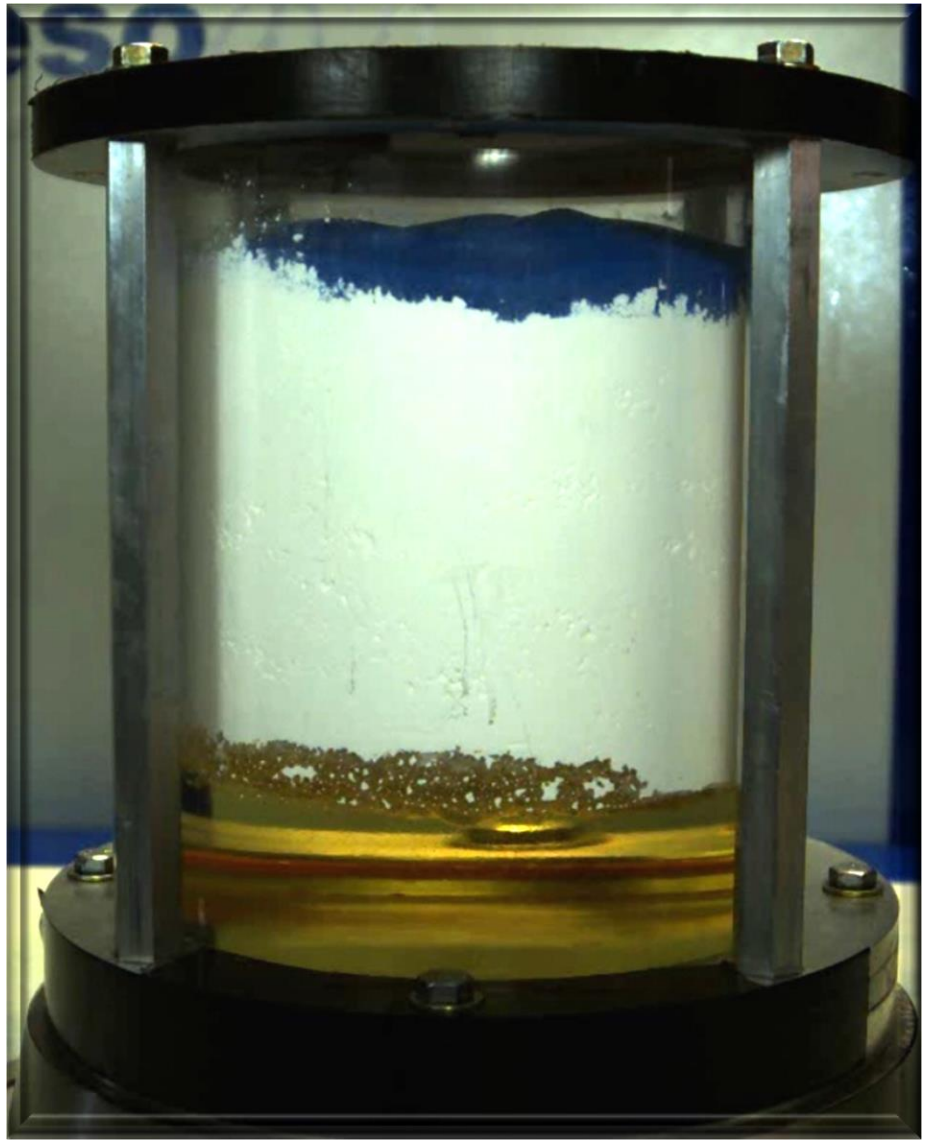
Demonstration of New

ess



Resonant Acoustic Mixing

- **New technology that uses sound wave energy coupled to the formulation medium to perform mixing process**
- **Bladeless process that produces Faraday instabilities within the medium for rapid and efficient blending**
- **Advantages**
  - Safety
  - Speed
  - More uniform ingredient dispersion
  - Better binder filler interaction
  - Not as limited by material viscosity
  - Reduced environmental impact
  - Mix inside the final item (Mix-in-Case)
  - Continuous Mixing (Large volumes from a small mixer)



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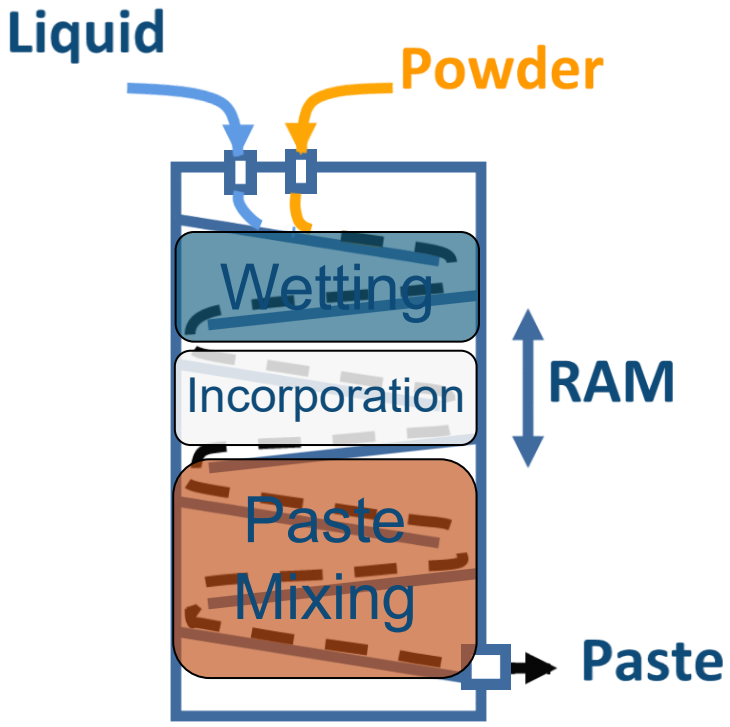
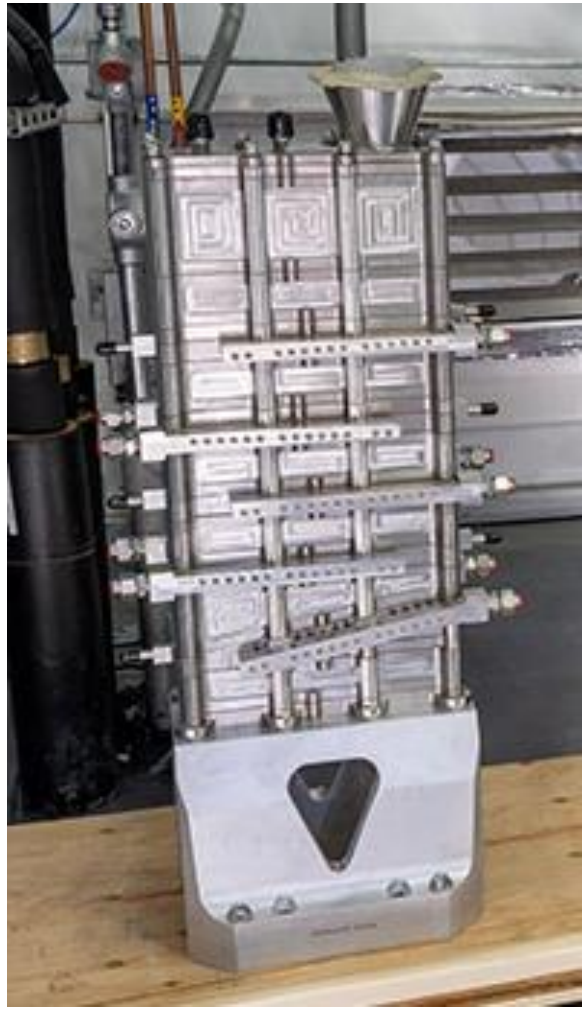
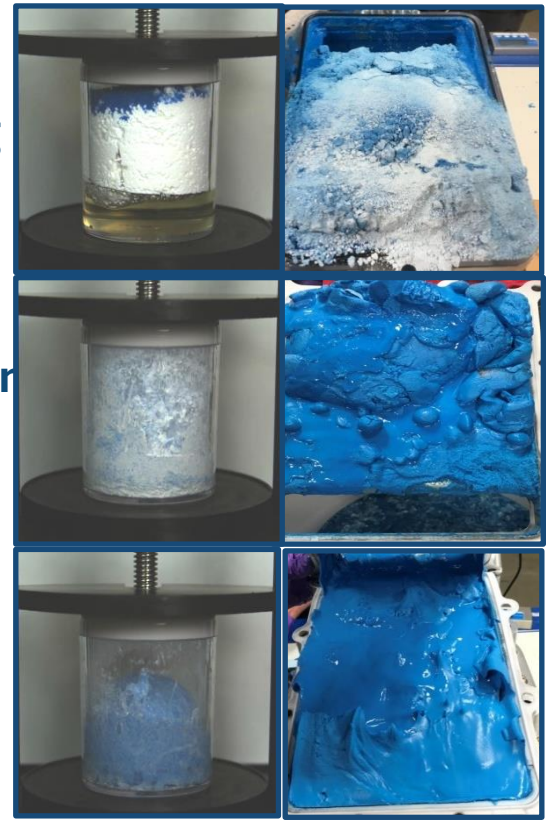
Continuous Resonant Acoustic Mixing (CRAM)







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Advantages of CRAM

- Overcome production limitations for RAM Batch Mixers
  - RAM5 Batch Size – 35Kg (Mixing Rates – 10-45 mins)
    - CRAM5 CRAM – 1.3Kg/ min (≈ 20 minute residence time)
  - RAM 55 batch Size – 420Kg
    - CRAM 55 - ~ 20Kg/min (≈ 20 minute residence time)

- Decouple material production rate from waste production rate.
  - Batch processing – The amount of material produced is tied to batch size and number of batches made
    - Batch process will produce 5-20% waste based on operation and the total batch size.
  - CRAM processing – The amount of material produced is tied to CRAM run time.
    - CRAM process produces the same small amount of waste regardless of run time
      - ≈ 25lbs of material during start up
      - ≈ 5lbs of material remain after run out
      - 4 gallons of soap and water cleaning solution + 4-5 gallons of rinse water

- Improved material consistency
  - Batch processing – If casting takes hours, the first item cast is not at the same state of cure as the last item cast
  - CRAM processing – Casting can take place as soon as the material exits the CRAM stack –
    - Every item cast can be at the same stage of cure

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RAM5 Set-up

- The earthquakes in 2019 damaged the RAM5 and the facility where it was housed
- The RAM5 mixer was reinstalled in a temporary facility

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RAM5 & CRAM Set-up

RAM 5 is outfitted to conduct both batch and continuous mixing

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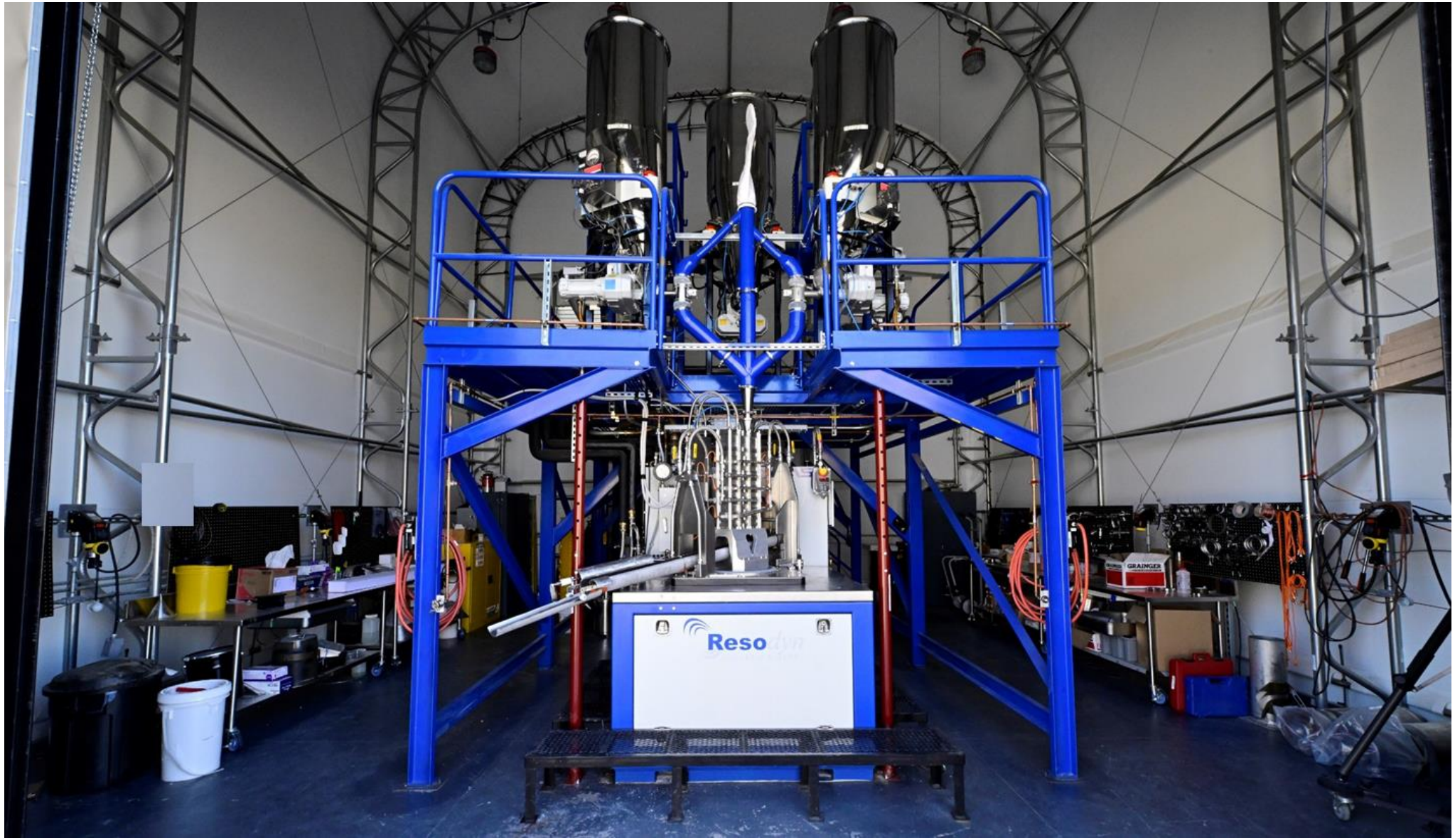
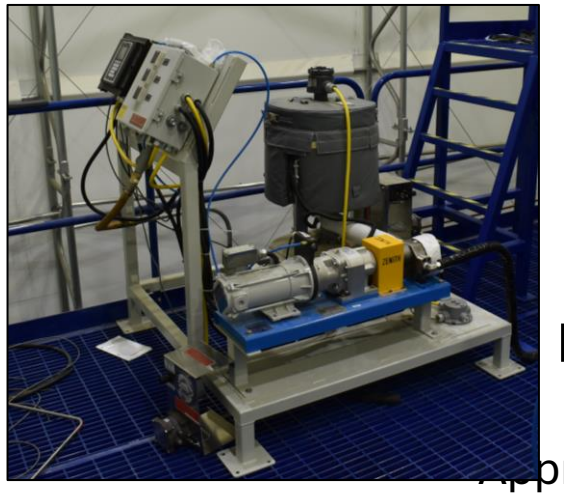
RAM5 & CRAM Set-up, cont.



Above the Stack

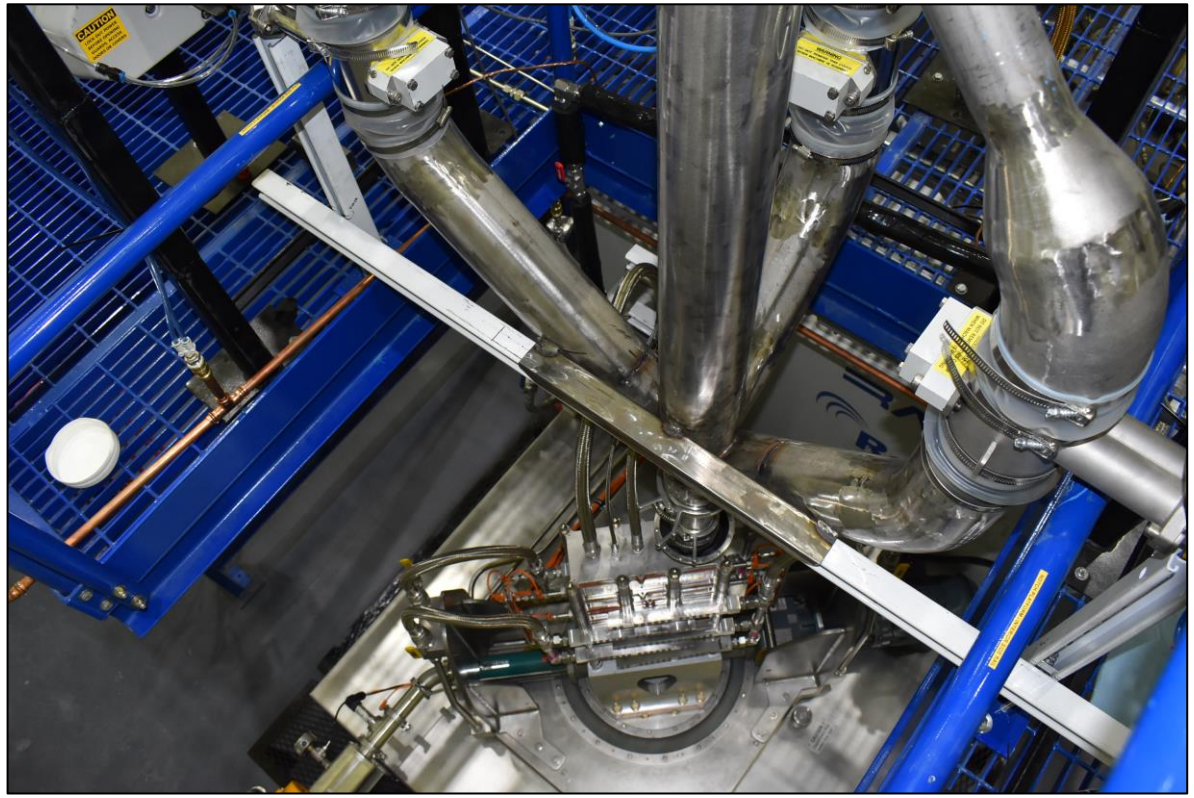
Three loss in weight solid feeders
(≈ 400lb/feeder)

Small capacity loss in weight liquid pump
(2 gallon reservoir)
and a direct feed progressive cavity pump
(4 gallon reservoir)



Large capacity loss in weight liquid pump (5 gallon reservoir)

Feeding the CRAM



4” stainless steel pipe from each solid feeder down to the CAM funnel

2” stainless steel pipe for pressure relief
1 um filter sock to reduce dusting

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Updated Liquid Supply Line Connections

Isolating the liquid feeder lines from the feeder platform improved solid feeder performance

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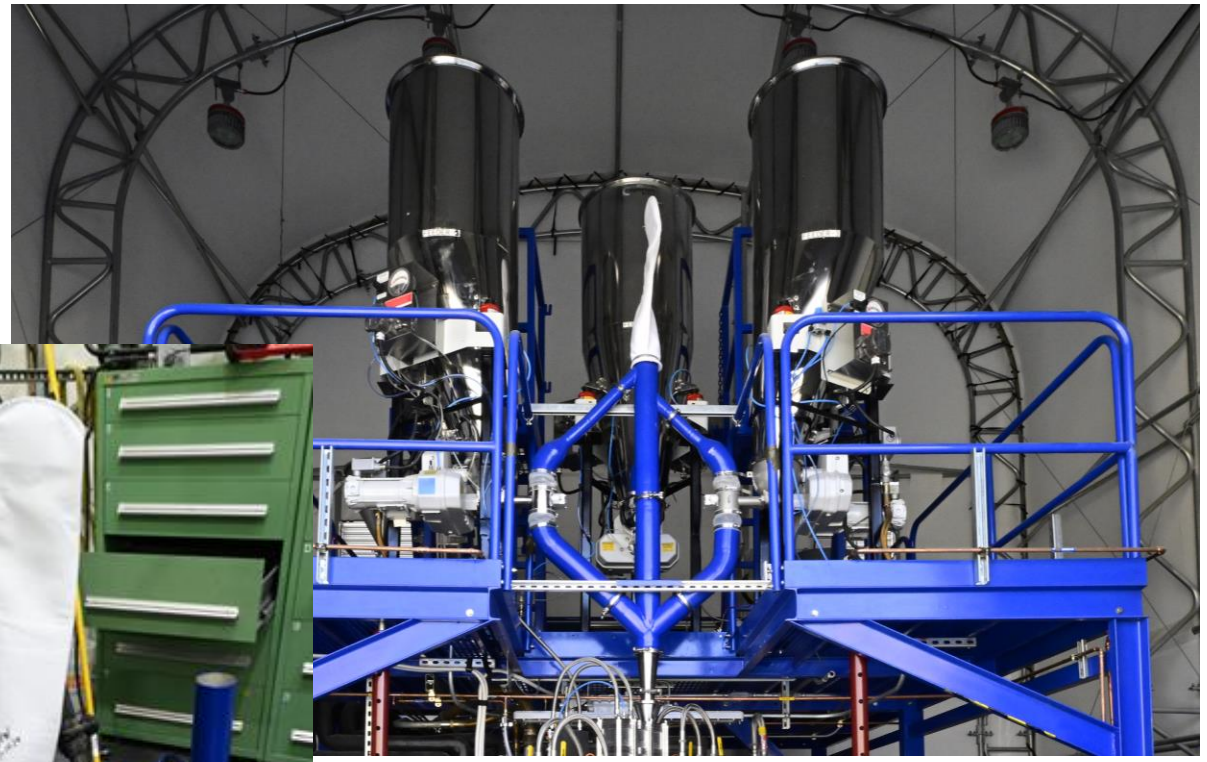
Updated Feeder Connections



Single piece construction was too heavy during disassembly and too difficult to keep clean

8-piece construction makes disassembly and cleaning much easier

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Feeder Modifications

Two different types of augers are used in the solid loss-in-weight feeders

Does not appear to effect material feed rate or variability

The diameter of all the augers had to be turned down approximately 0.080” to create a 0.10” clearance between the auger and the housing tube

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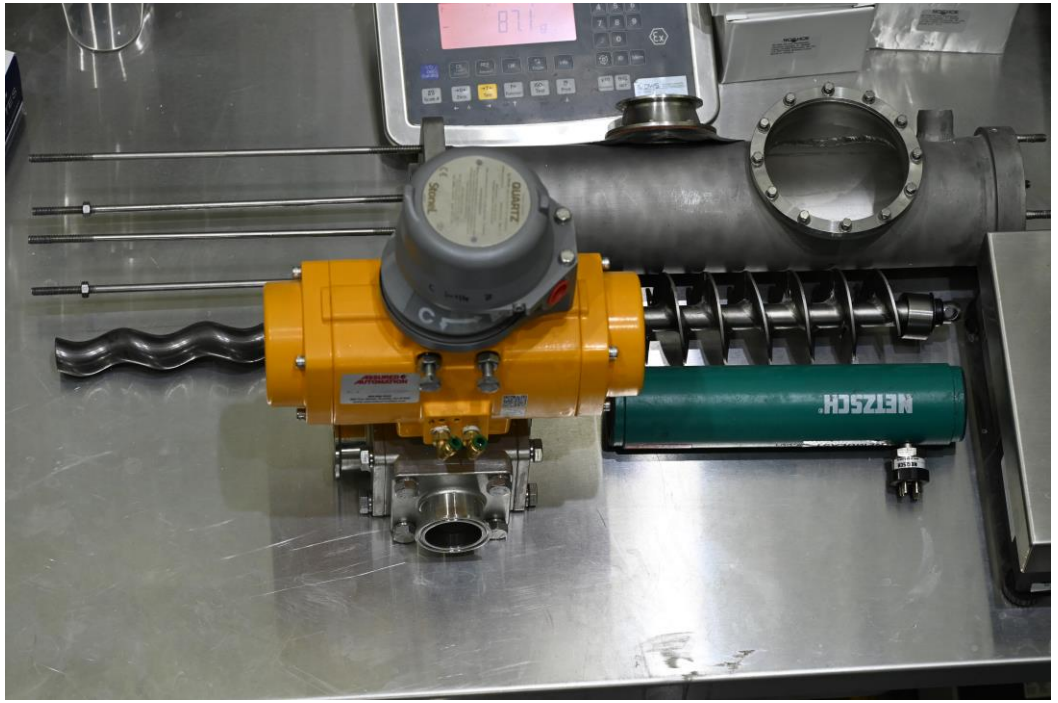
Original Off-take design



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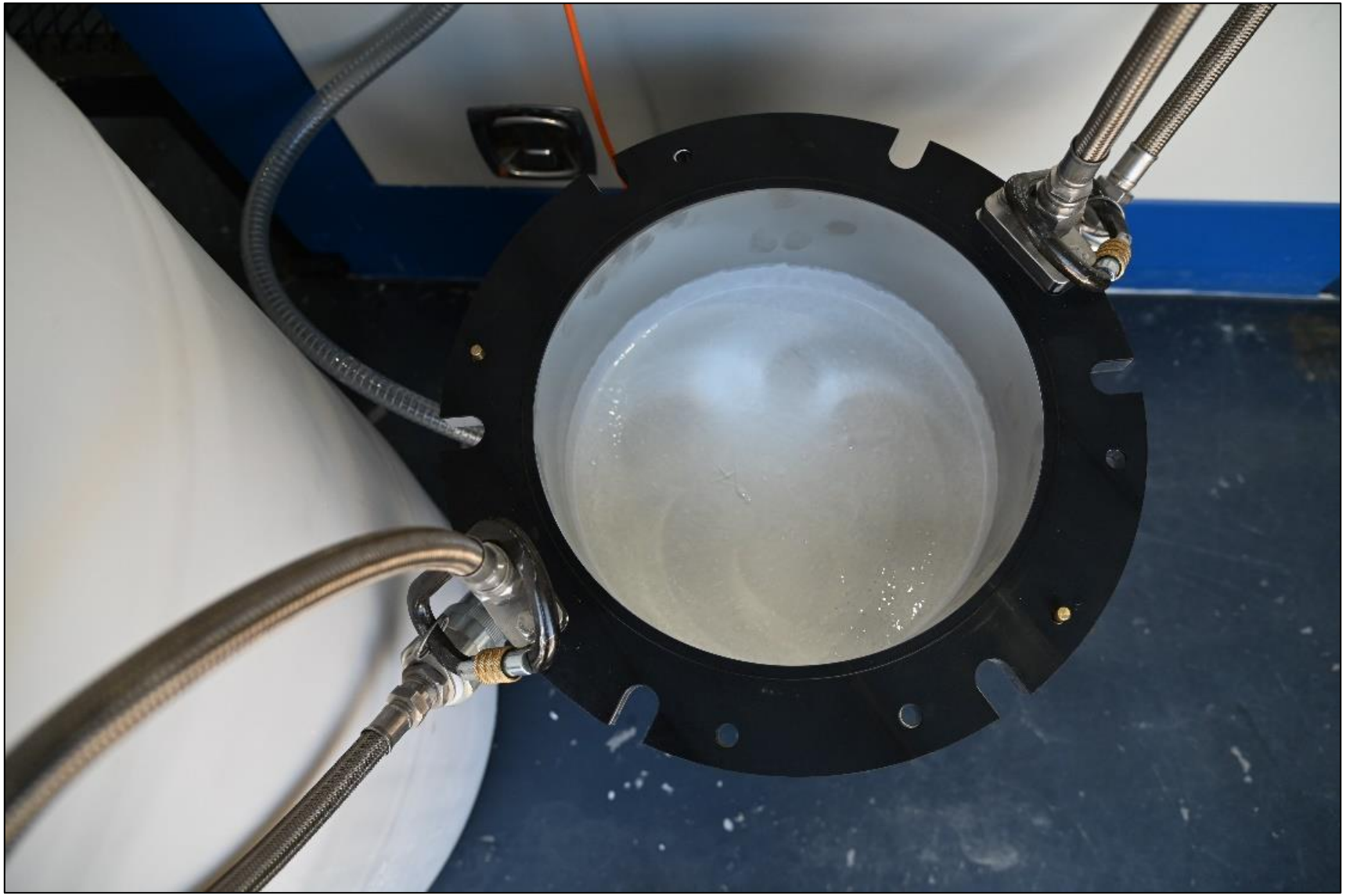
Material Degassing



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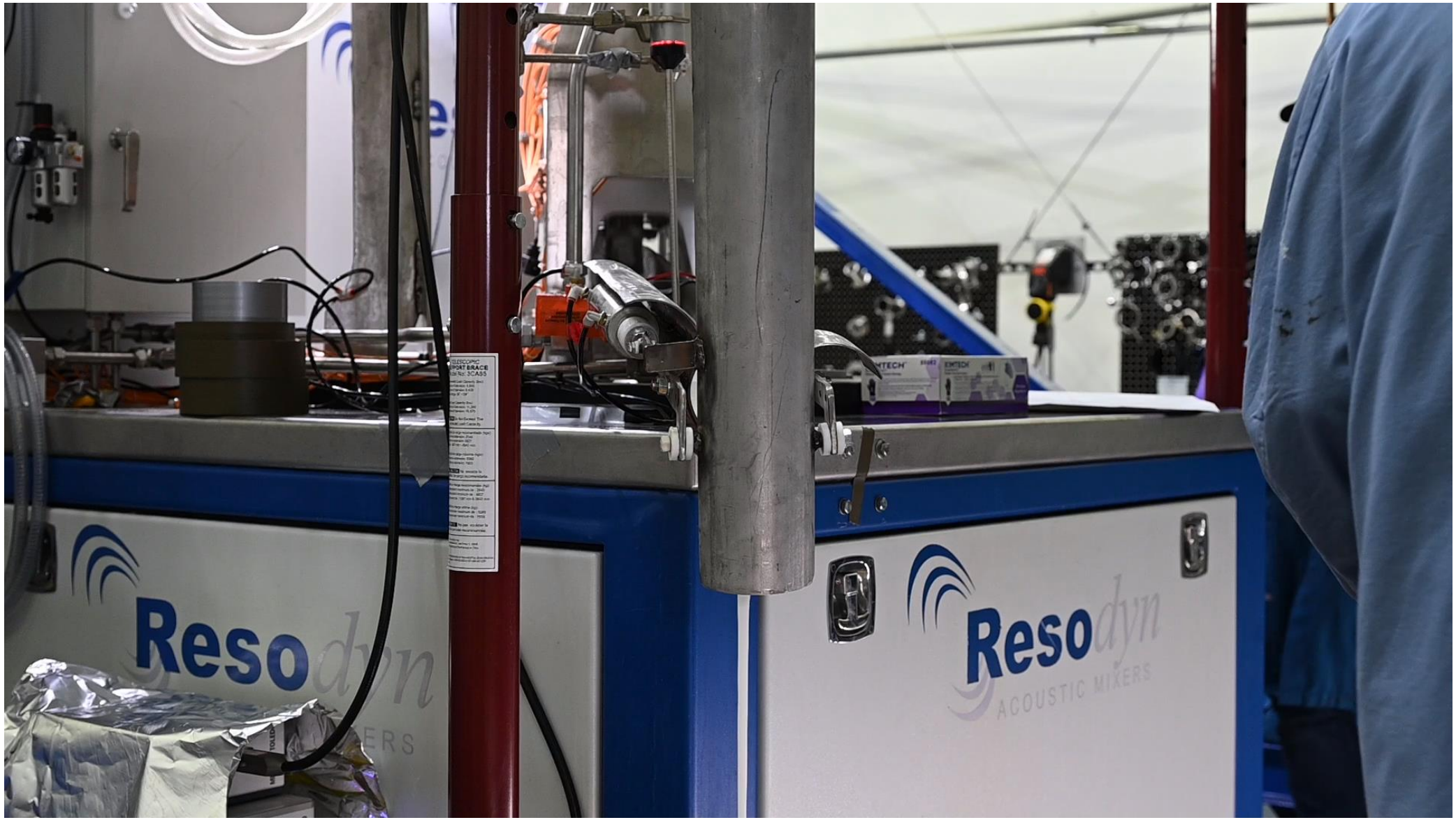
Temporary alternative Offtake System

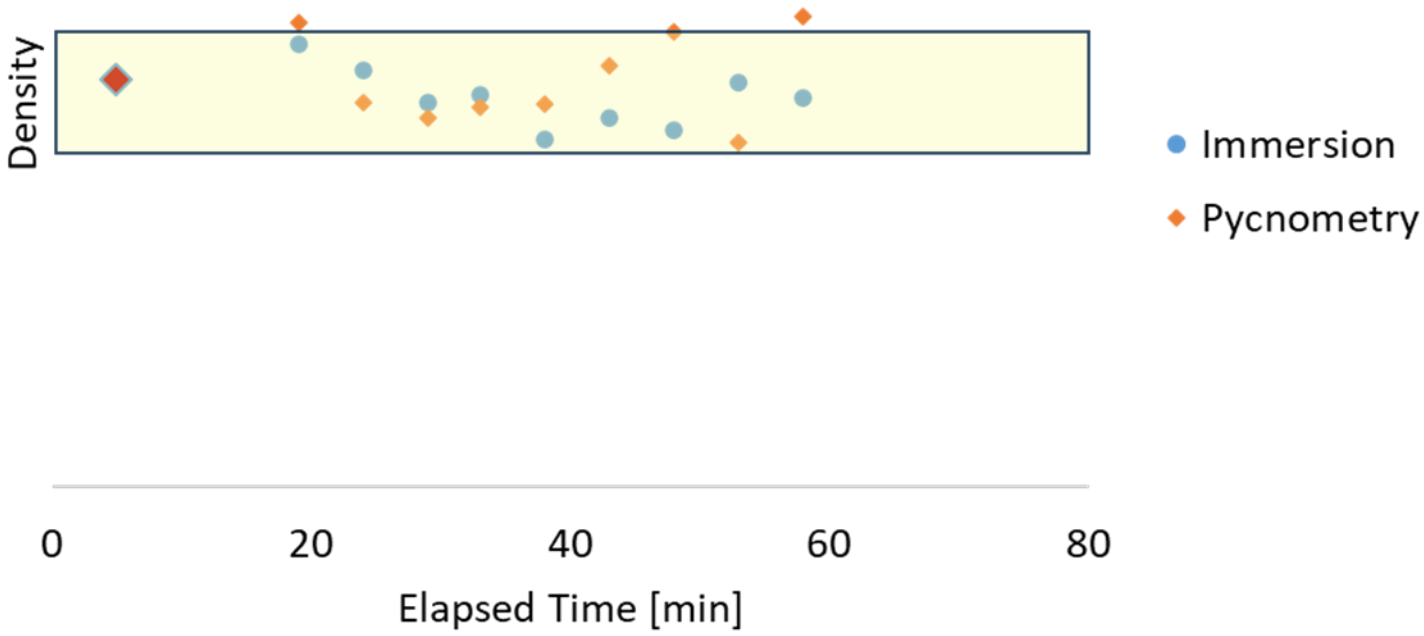
Air powered vibration

Two collection positions for in-spec and out of spec material

System in Action



Material A Data



Immersion density variation is within normal spec. limits for this run condition

He Pycnometry density variation is slightly outside normal spec. limits

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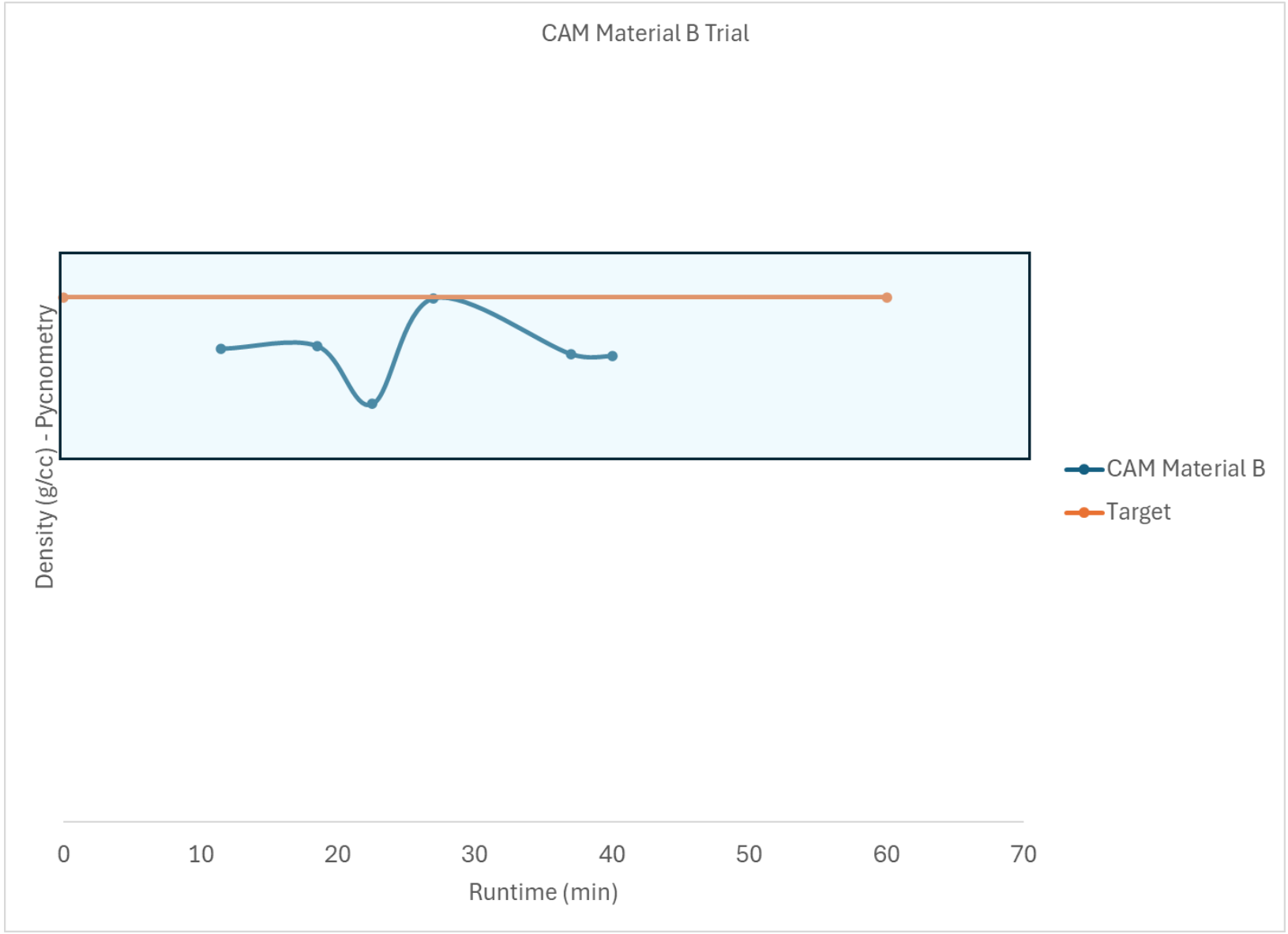
Material B Data

The Density of the material is lower than the target but within the range expected for a production material.

The Lower Solids may be linked to plasticizer pump setting



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Starting, Stopping and Restarting

Operation Steps

- Start process to make ≈ 50lbs of material
- Perform soft machine stop (Simulate normal process interruption)
- Restart process to make 50lbs of material
- Perform hard machine stop (simulate power outage)
- Restart process to make 50lbs of material

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Starting, Stopping and Restarting

Operation Parameters

- Each process restart followed the same process parameters

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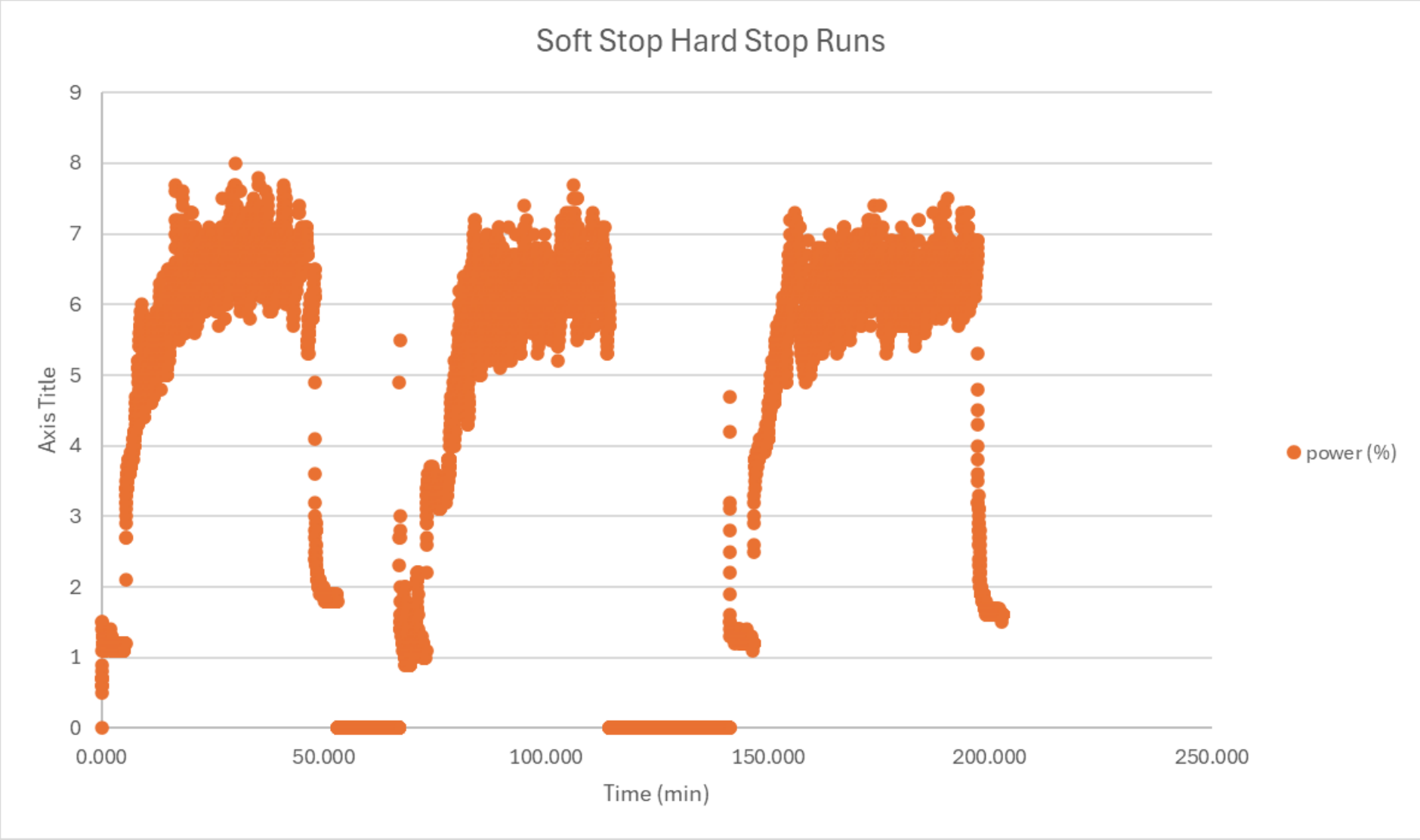
Starting, Stopping and Restarting



Machine Data Observations

- The %power required by the machine was very stable through each process

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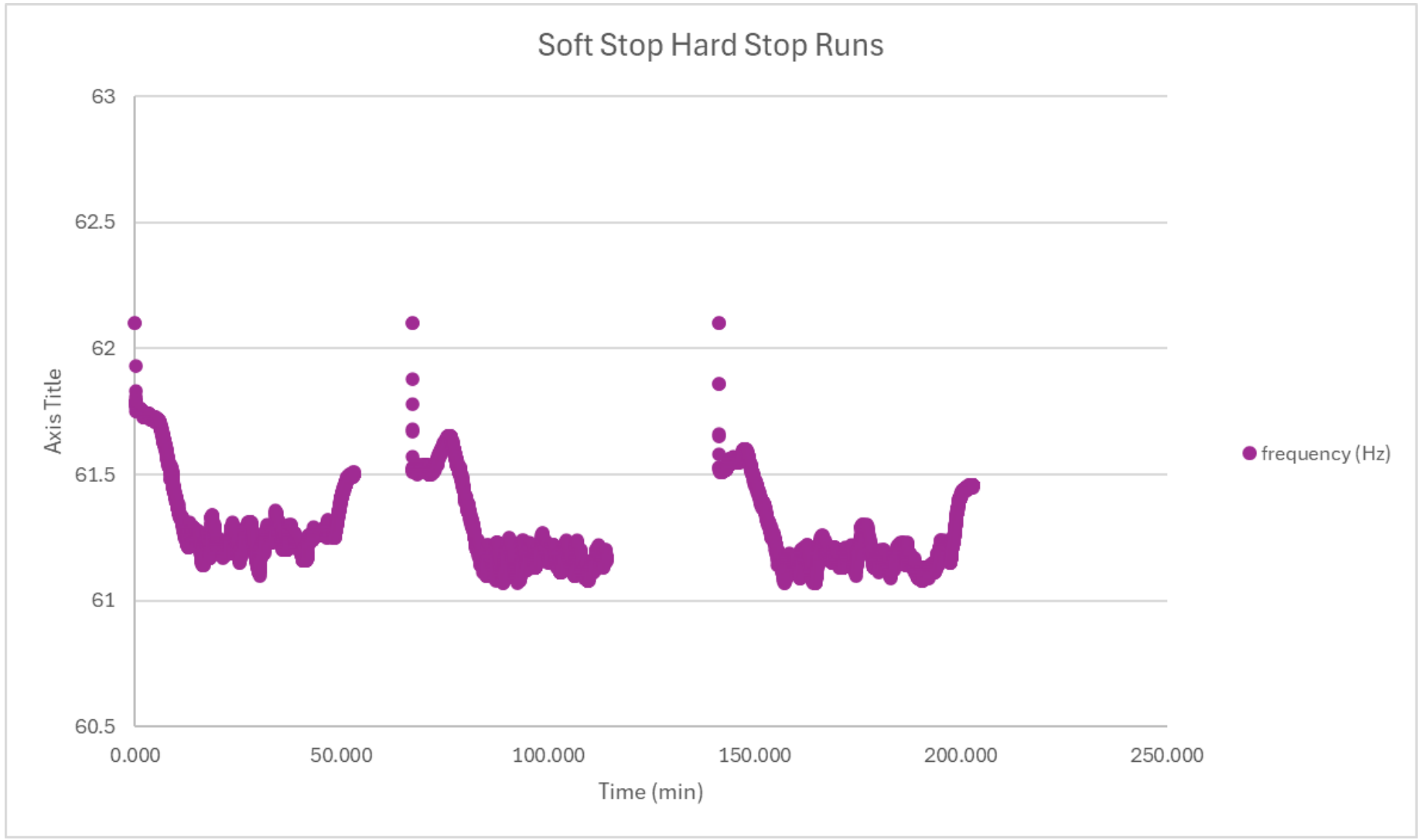
Starting, Stopping and Restarting



Machine Data Observations

- The frequency data suggests no issues with material backing up inside the stack after both the soft and hard stops

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Starting, Stopping and Restarting

Operation Steps

- Start process to make ≈ 50lbs of material
- Perform hard machine stop (simulate power outage)
- Restart all the feeders at recipe rate and make 40lbs of material at 1.25Kg/min
- Make 30lbs of material at 1.0 kg/min

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Starting, Stopping and Restarting

Operation Parameters

- The restart involved starting the RAM5 and all the feeders at recipe rate

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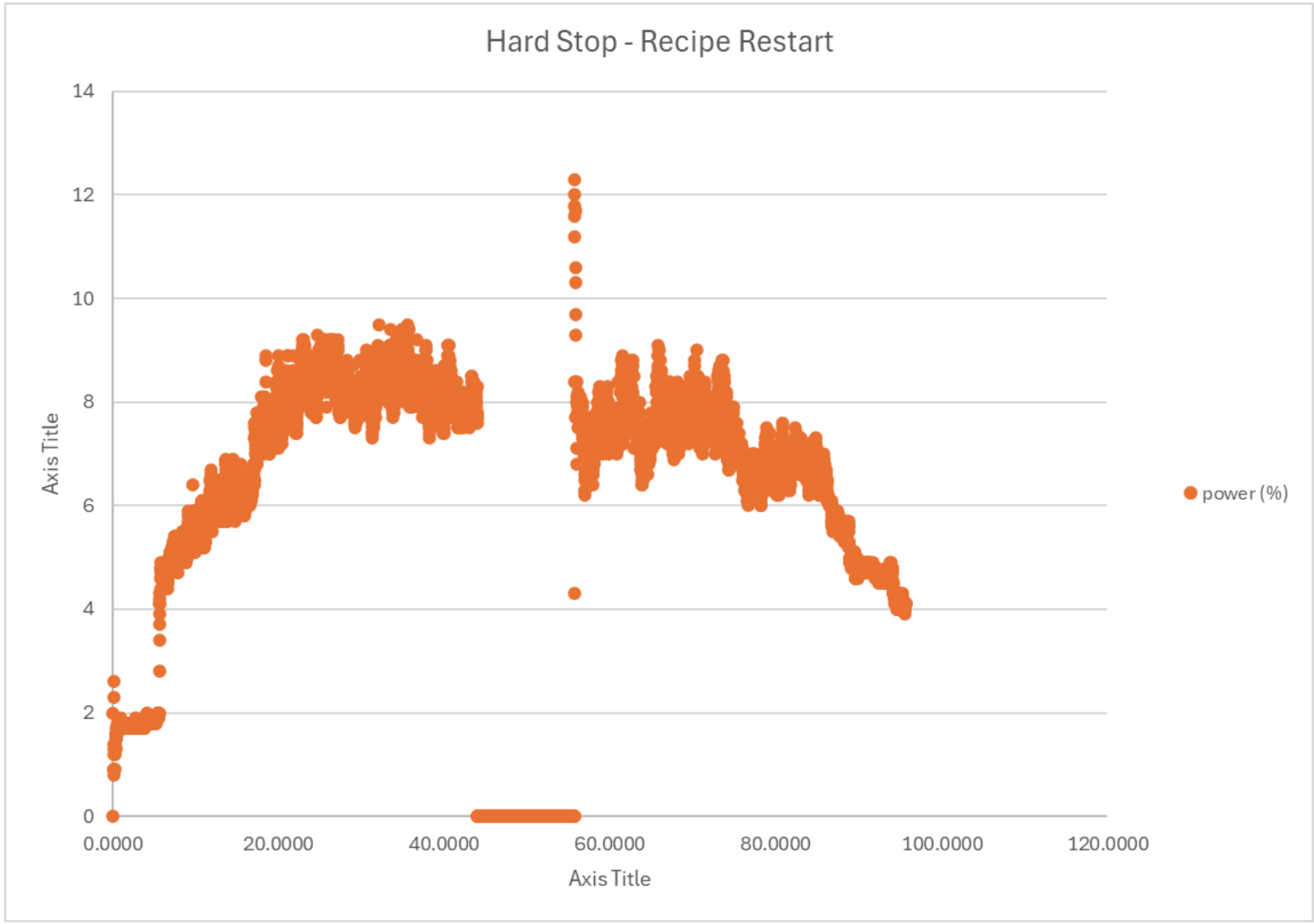
Starting, Stopping and Restarting



Machine Data Observations

- The %power required by the machine was very stable during the restart
- As expected, the %power is reduced at the lower feeding rate

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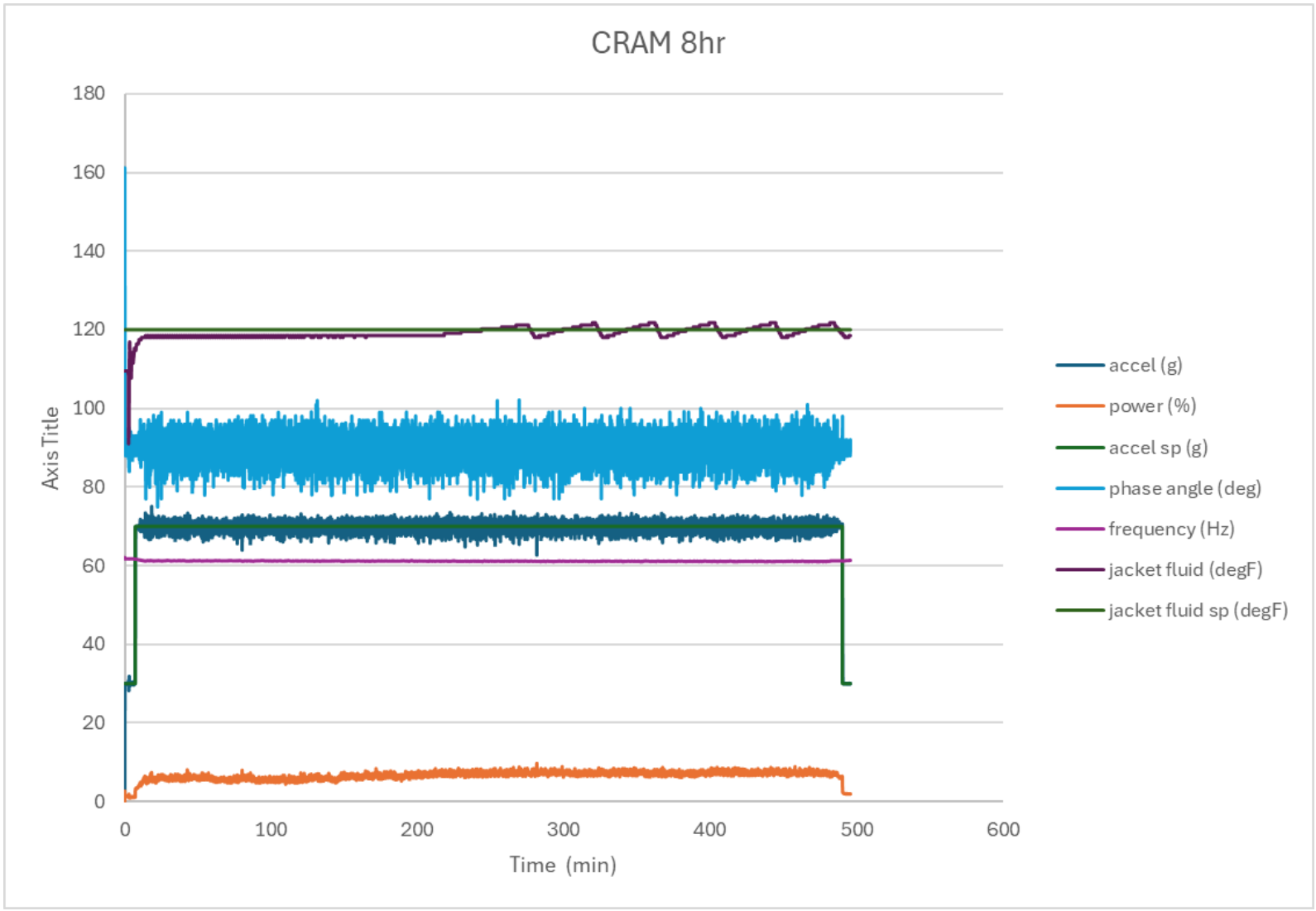
Starting, Stopping and Restarting

Machine Data Observations

- The frequency data suggests no issues with material backing up inside the stack after the hard stop and recipe restart

8hr Run Data (Machine)



Operation Steps

- Start process to make material continuously for 8 hrs

- Collect samples for analysis:
- 5 min increments during start up process
- Every 30 minutes after reaching recipe rate
- 5 min increments, 15-20 minutes after refilling the feeders

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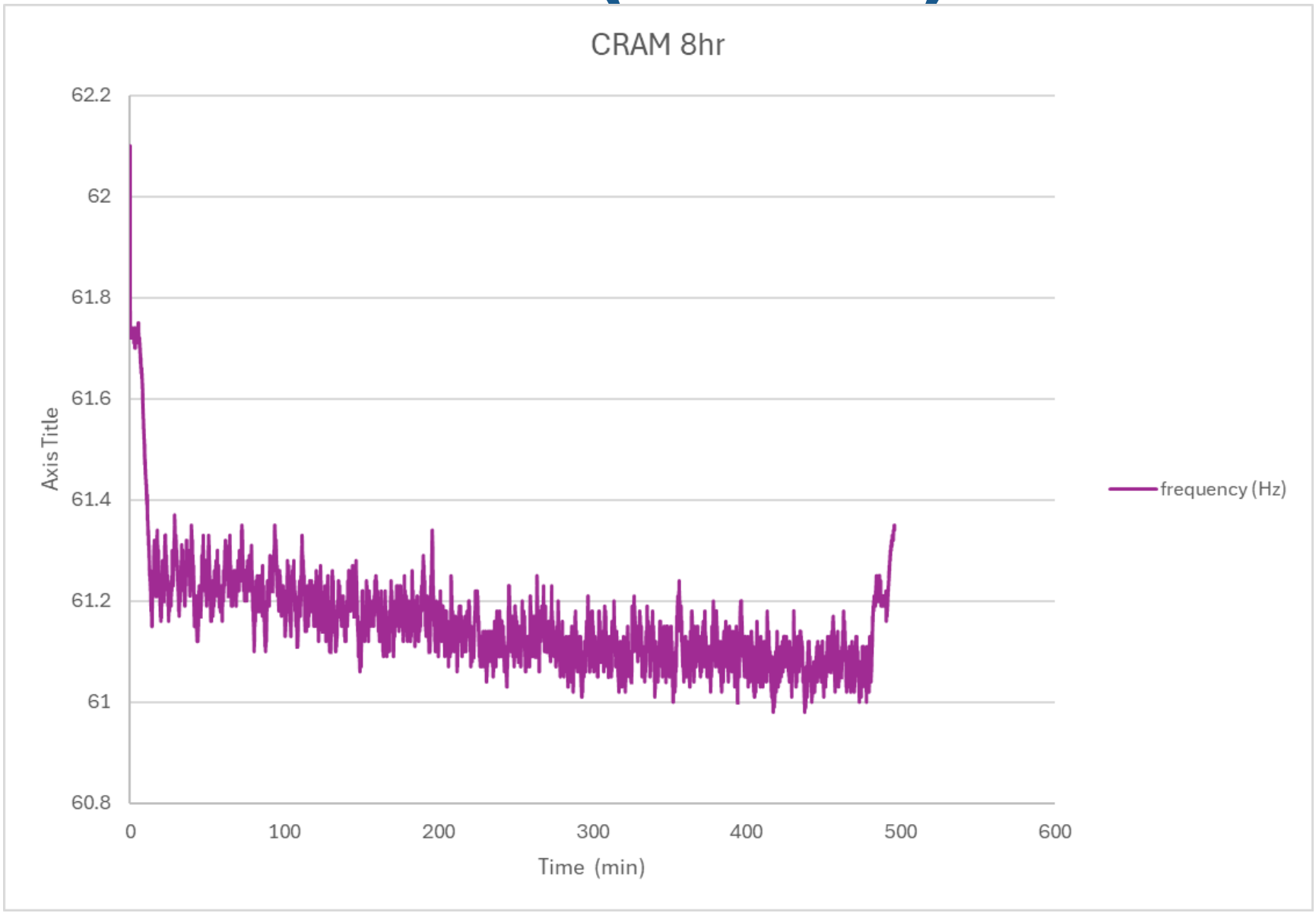
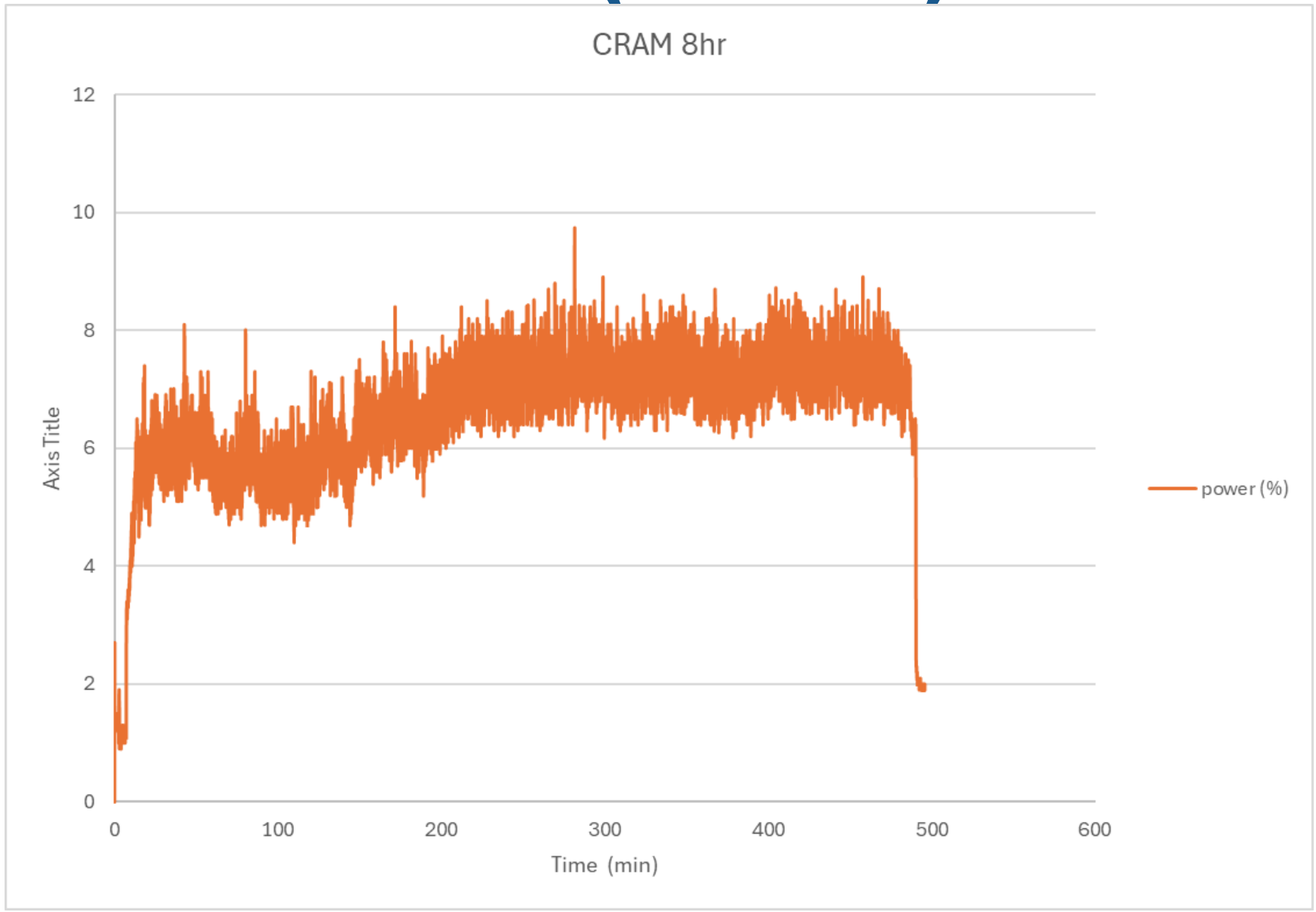
Recent 8hr Run Data (Machine)



Recent 8hr Run Data (Machine)



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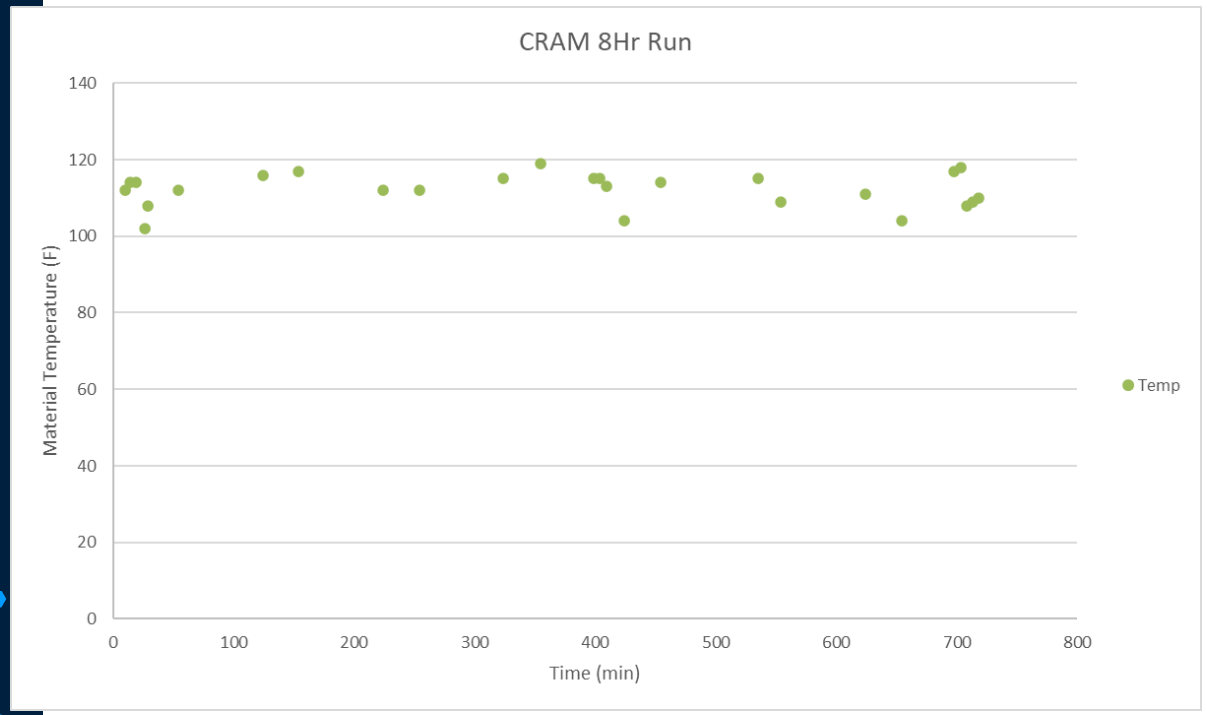
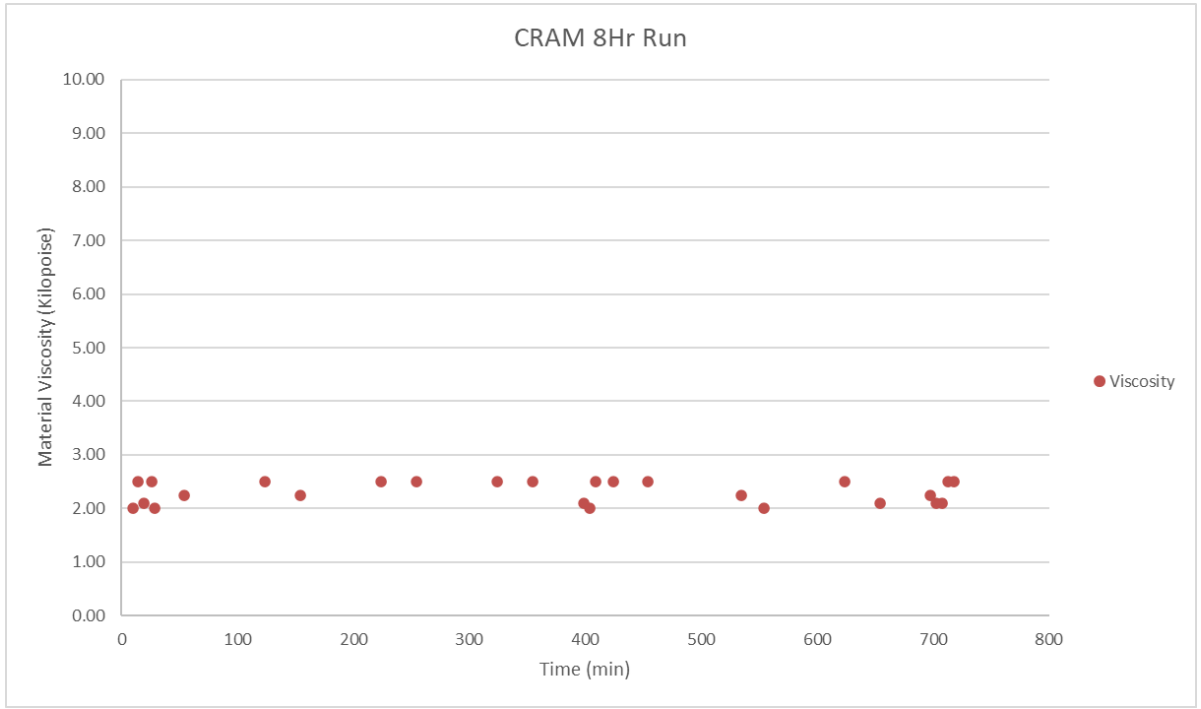
Recent 8hr Run Data (Material)





Temperature measured by hand-held IR thermometer
Total Machine Run Time – 8.5Hrs
Temperature is essentially unchanged over 8hrs
Viscosity is unchanged over the 8hr run

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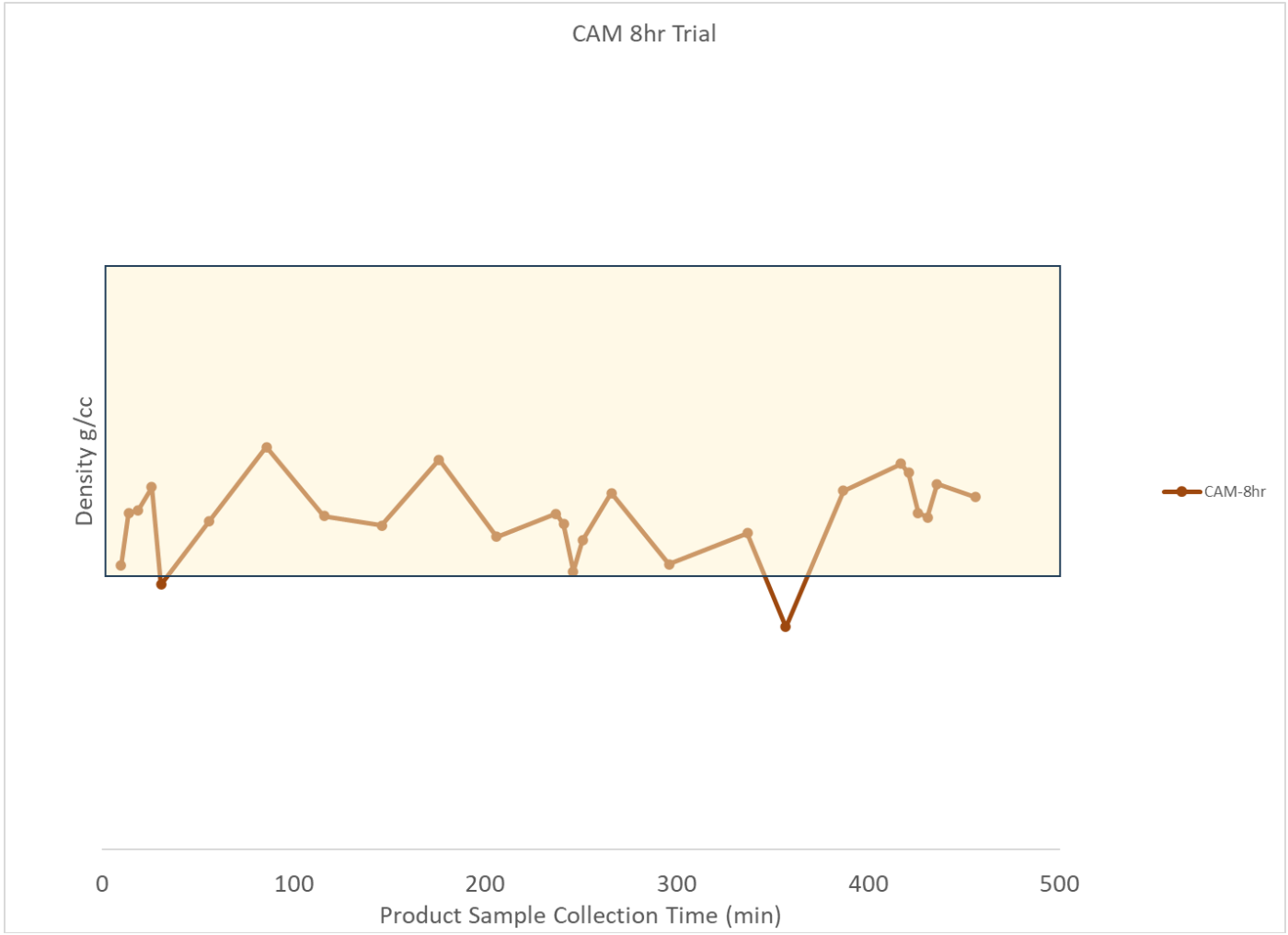
Recent 8hr Run Data (Material)



Density measured by helium pycnometer

Total Machine Run Time – 8.5Hrs

Samples were collected every 5 minutes at start up, every 30 minutes during the run and in 5 minute intervals when reloading the feeders

Only two samples over 8hrs fell outside the target range for the material.

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Conclusions

- More than 15 CRAM operations have been completed successfully
- We have demonstrated the ability to make composite material with separate binder compositions.
- To date, all the trials indicate that the CRAM system can deliver material at 1.25Kg/min with accuracy adequate for production.
- Starting and stopping the process, both controlled and unexpected seem to have little effect on the RAM5 operation.
- The downstream process of removing air from the mixed composite prior to casting final products is the area that needs the most development.

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