From Waste to Power: Biosludge Atomization for Efficient Energy Conversion

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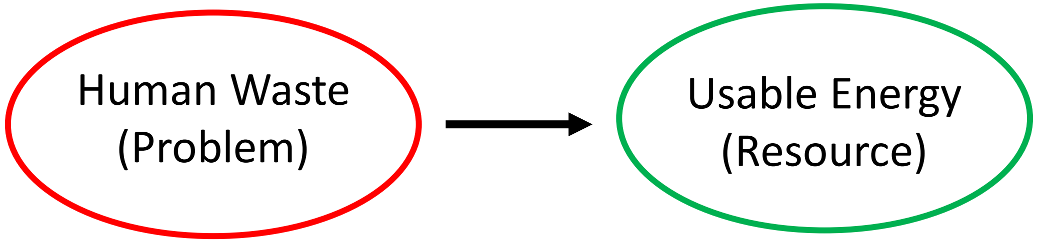
Objective: human waste → usable energy

- **Goal:** Efficient conversion of human waste to usable energy by injecting atomized biosludge into a boiler



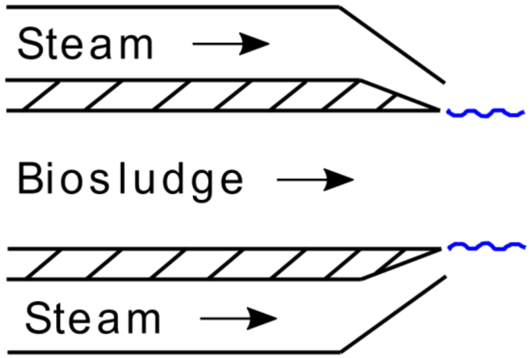
  - Biosludge**:** processed human waste sludge (output of waste processing facility)
  - Boiler: energy harvesting equipment
  - Atomization: provides high surface-area-to-volume ratio for drying and combustion
- **Our work:** Computational demonstration of an atomizer design which can effectively process highly concentrated, non-Newtonian biosludge
  - Using CFD to model and optimize the atomization process

Importance: energy + sanitation

- Other methods of energy conversion
  - Digestion, gasification, pyrolysis
  - Disadvantages: long waits, dilution, drying operations
- Advantages of concentrated biosludge injection
  - Increased conversion efficiency, reduced water usage, reduced fossil fuel emissions
- Addresses numerous global issues
  - Fossil fuel scarcity
  - Clean water shortage
  - Undersized waste management facilities
  - Food safety
  - Disease control
  - Life-saving energy-production in developing countries

Atomizer design considerations

- Twin-fluid atomizer with steam as assisting gas



Typical twin-fluid atomizer design

- Steam shear → biosludge instabilities → droplet formation
- Steam → reduces biosludge viscosity → effective atomization
- Steam → reduces boiler efficiency (heat sink + source of non-combustibles)
- Balance sought: minimal steam usage + effective atomization

Atomizer CFD model

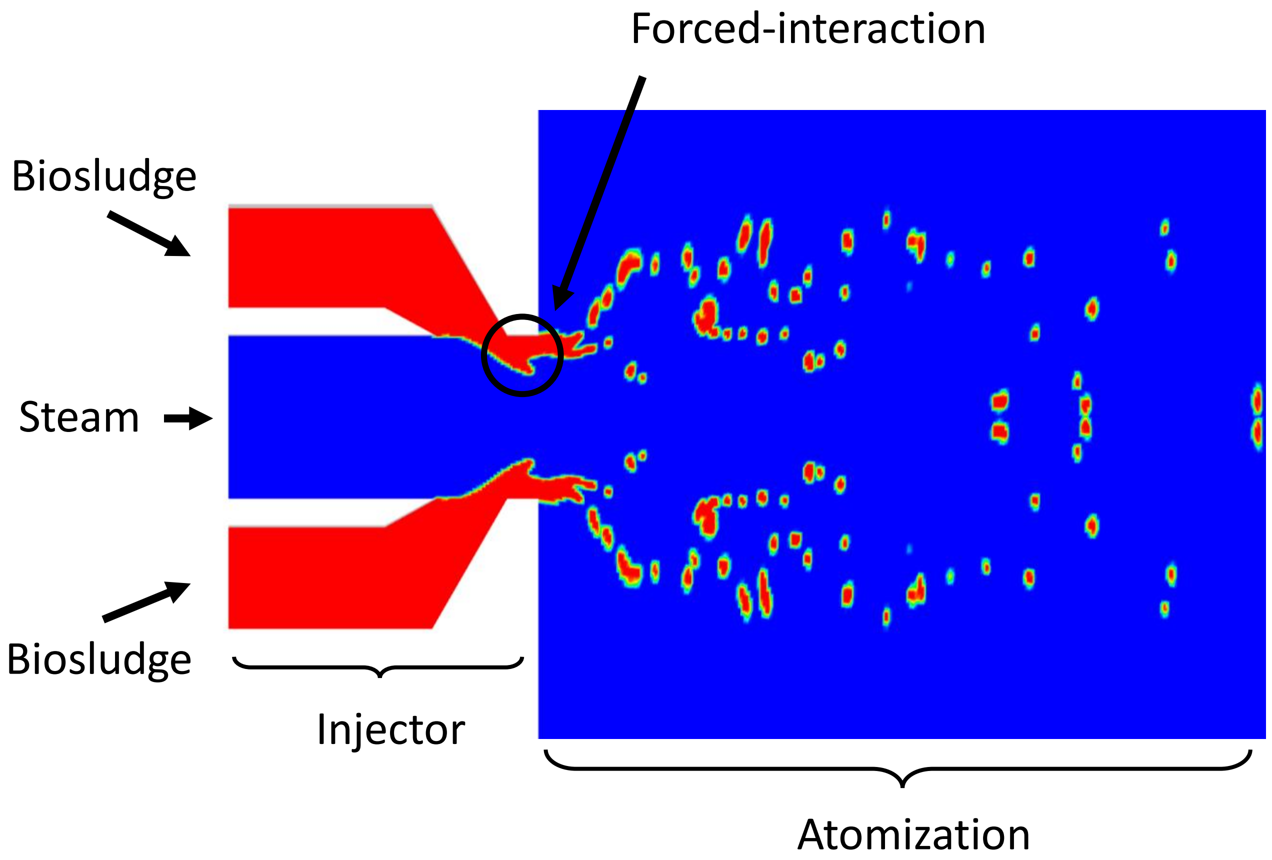
1. Typical design: steam flow outside
   - Worst atomization

2. Inverted design: steam flow inside
   - Better atomization

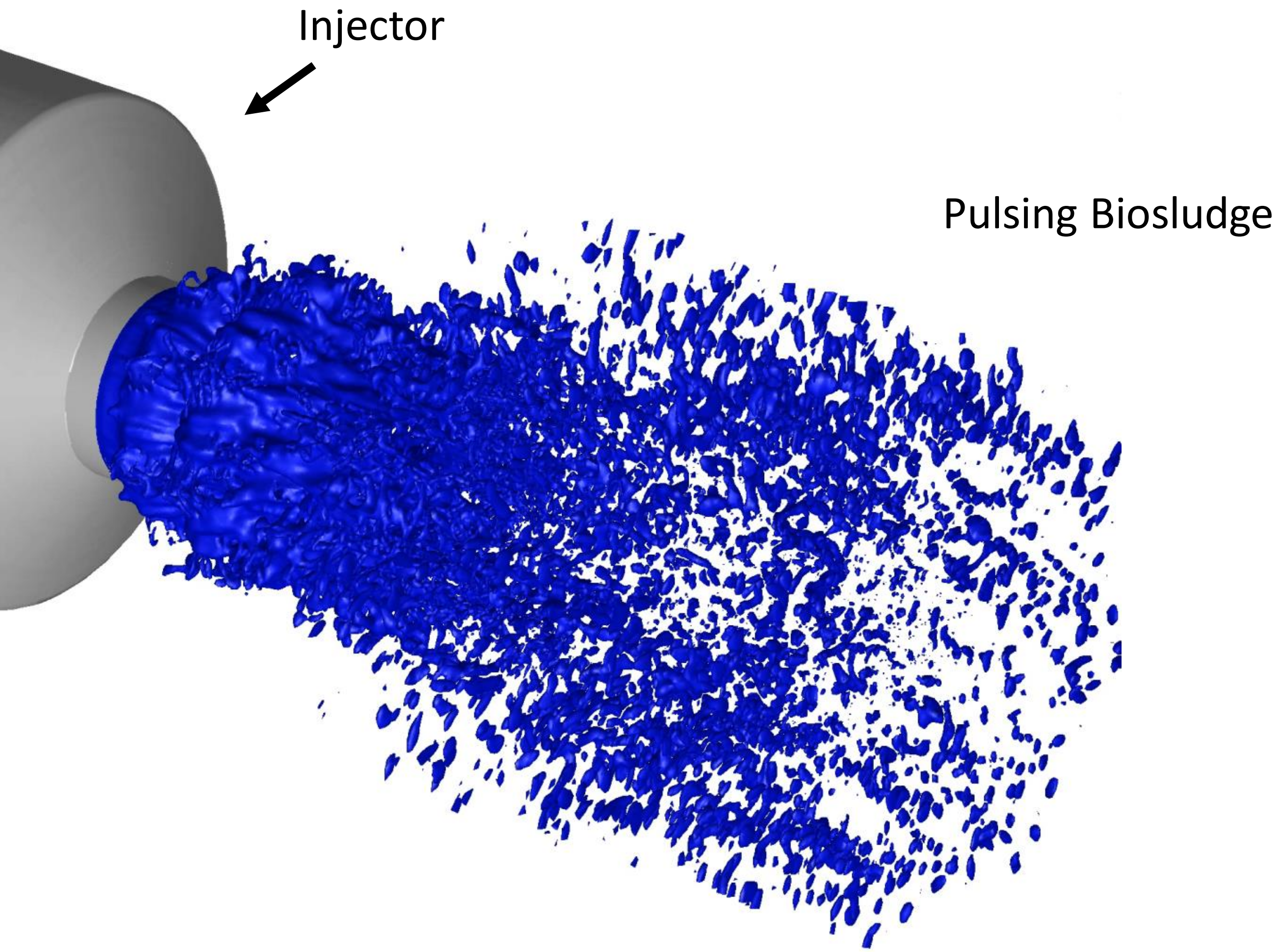
3. Inverted + forced-interaction
   - Best atomization

Current CFD model:

- Coarse mesh for controller tests
- Finer mesh for studying system



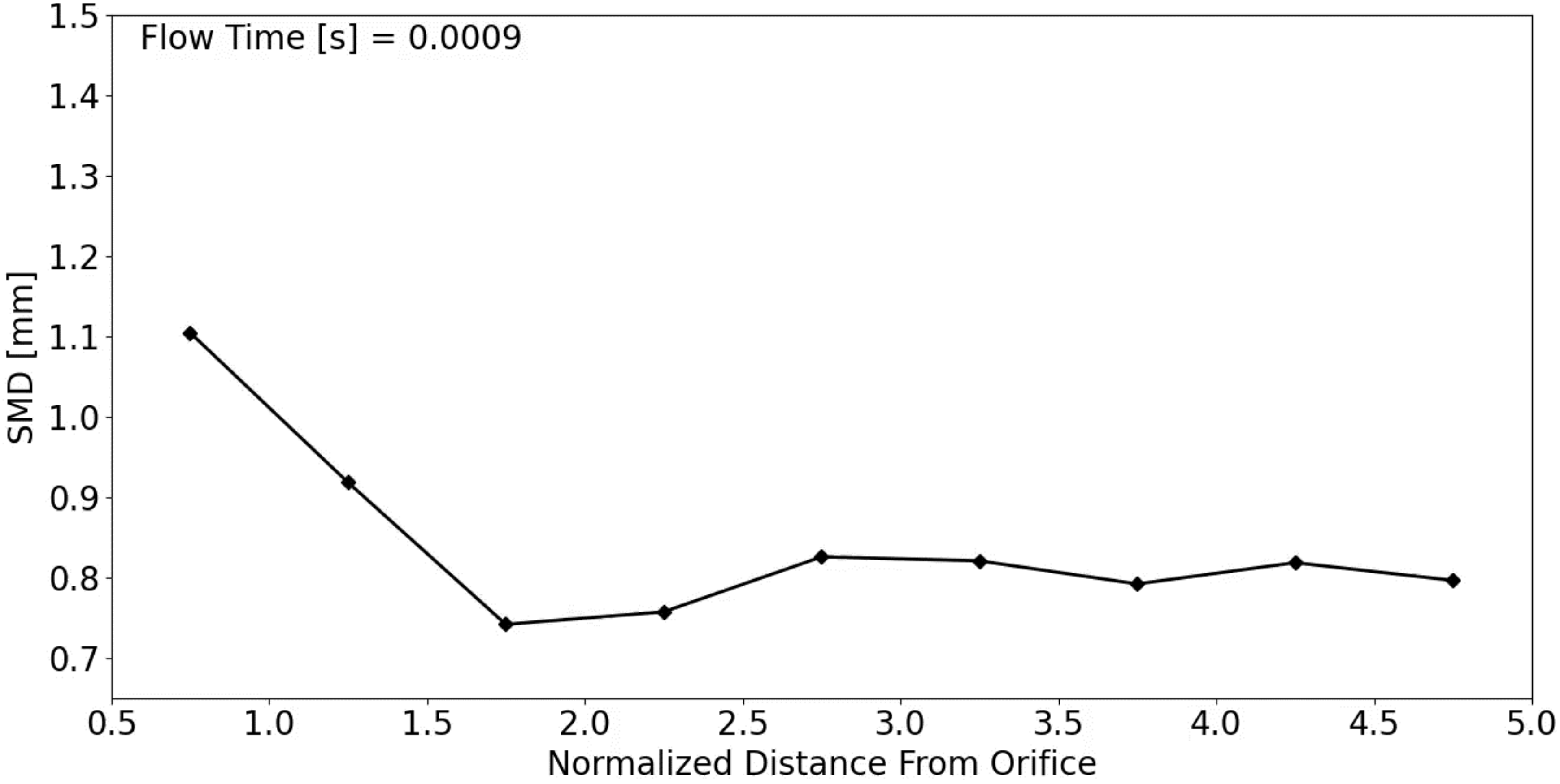
Inverted, forced-interaction design → pulsing biosludge



- Interfacial unsteadiness → **pulsing flow** → amplified growth of instabilities
- The pulsing nature of the system leads to better atomization

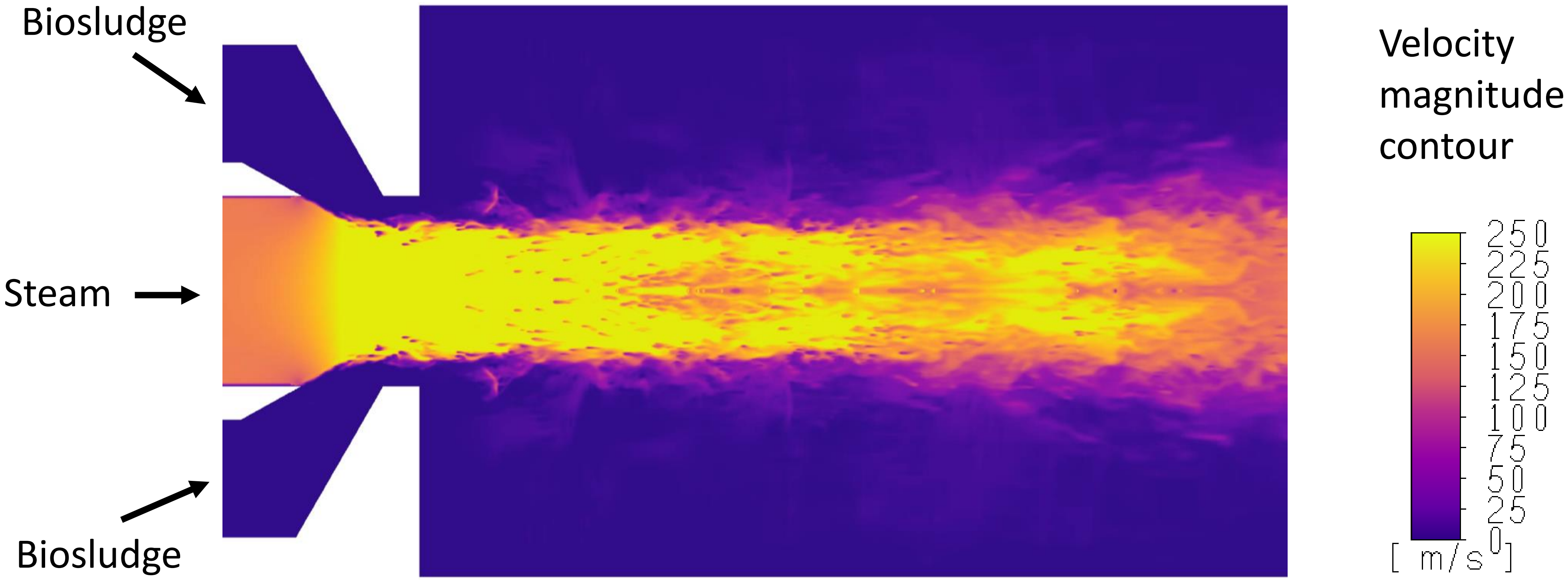
Biosludge doing “the worm”

- Waves of biosludge move through the domain



Steam flow accelerates through nozzle exit

- The biosludge decreases the exit area for the steam, causing the steam to accelerate as it exits the nozzle
- Biolsudge droplets near centerline move much faster than those farther away



PID control adjusts for varying biosludge viscosity

- Difficulty: viscosity of biosludge varies widely
- High viscosity → large pressure drop restricts flow → poor atomization quality
- Smart atomization: adjust flows to account for dynamically changing fluid properties with 2 proportional integral derivative (PID) controllers

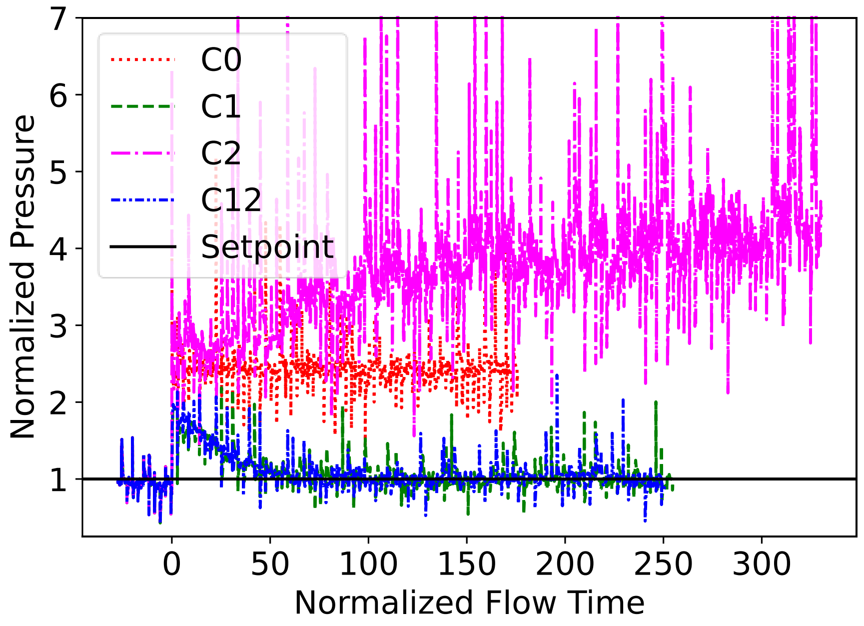
1. Biosludge flow controller (C1)
    - Automates flow of biosludge based on pressure drop
    - Objective: maintain constant biosludge pump requirement for varying viscosity
2. Steam flow controller (C2)
    - Automates flow of steam based on droplet size
    - Objective: maintain atomization quality for varying viscosity

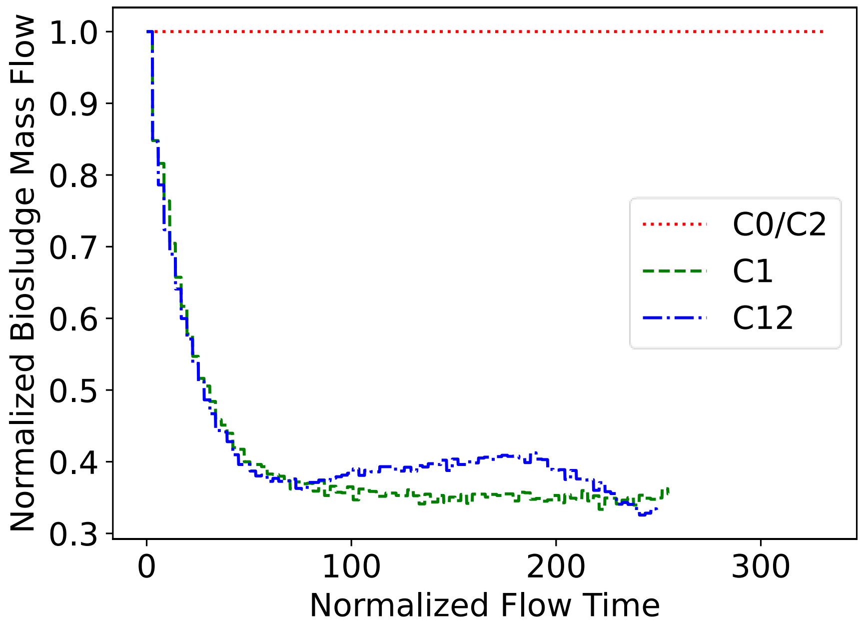
Controllers tested through 100x viscosity increase

- Viscosity increase: 0.05 → 5 kg/m-s at Normalized Flow Time = 0
- Before viscosity increase, all tests only use C1
- After viscosity increase, four scenarios evaluated
  - C0 = no controllers
  - C1 = only C1 controller
  - C2 = only C2 controller
  - C12 = C1 + C2 coupled controller system
- Recall…
  - C1 = biosludge flow controller
  - C2 = steam flow controller

Biosludge flow controller → pressure returns to setpoint

- C0 → pressure increases by 150%
- C2 → pressure increases by 320%
- C1, C12 → biosludge flow decreases, **pressure returns to setpoint**
- Conclusion: C1 necessary to maintain constant biosludge pump requirement

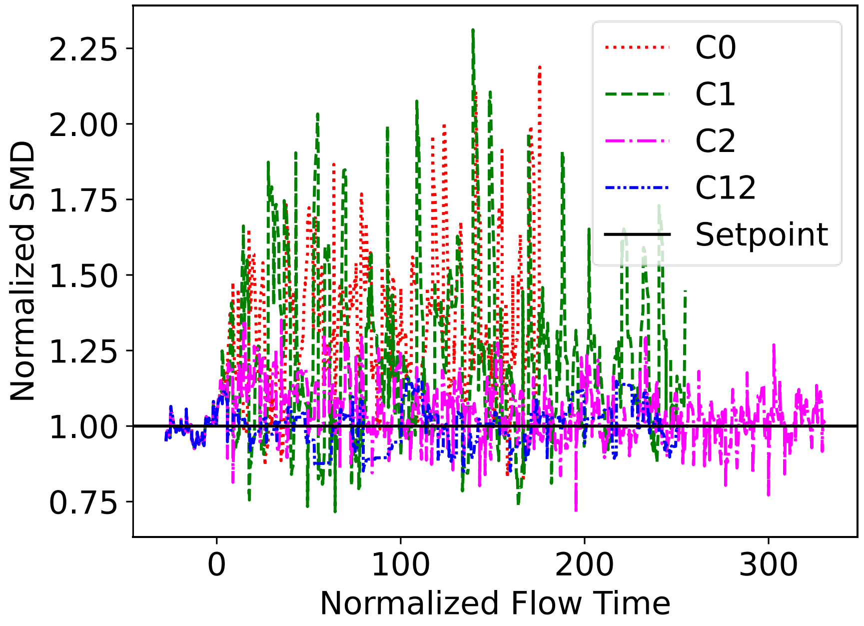


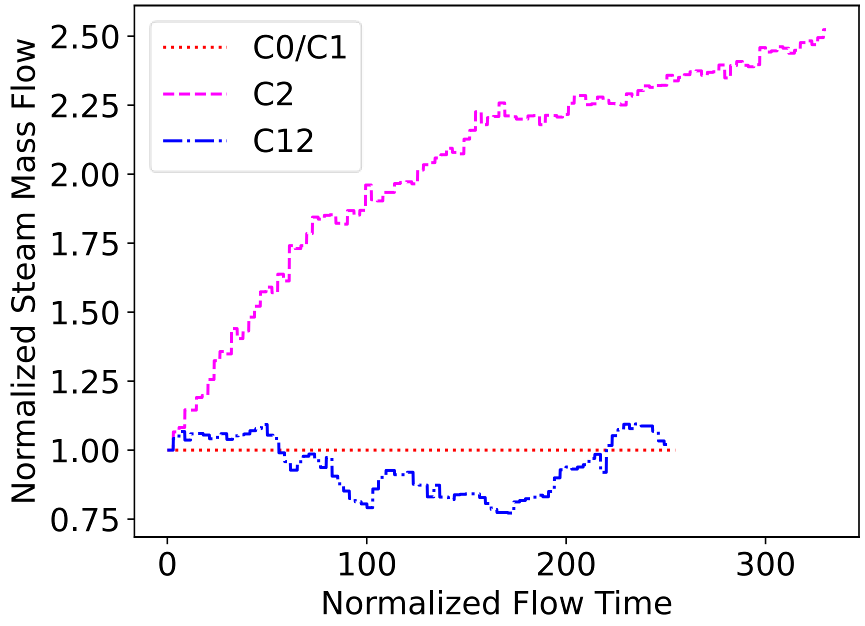


Steam flow controller → maintain atomization quality

- C0 → SMD increases by 40%
- C1 → SMD increases by 20%
- C2, C12 → steam flow adjusts, **SMD returns to setpoint**
- Conclusion: C2 is necessary to maintain atomization quality

Result: We demonstrate the efficacy of the coupled controller system and need for *both* C1 and C2





Christian worldview

- Exploration
  - Discovering the beauty and complexity in God’s world
  - Seeing and sharing the glory of God displayed through His created work
- Stewardship
  - We don’t worship the environment – we cultivate it
  - Use resources for helpful, constructive purposes
- Flourishing
  - Producing needed energy
  - Making a cleaner, safer world
  - Providing life-saving resources

Conclusion

- Objective
  - Efficiently convert human waste to usable energy by injecting atomized biosludge into a boiler
- Motivation
  - Environmental stewardship (energy + sanitation) → human flourishing
- Valuable contributions
  - Inverted, forced-interaction design improves atomization quality
  - Coupled controller system maintains relatively constant atomization quality for 100-fold increase in biosludge viscosity
- Future work
  - Improve and experimentally validate CFD model
  - Add variable nozzle geometry

Questions?

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