From Waste to Power: Biosludge Atomization for Efficient Energy Conversion

LIBERTY UNIVERSITY

Ph.D. Student: Daniel Wilson, Advisor: Dr. Wayne Strasser

Background

Two Problems: 1) Ever-increasing amounts of human waste created 2) enormous energy needs in our modern world
- Both issues can be addressed with technology to convert human waste to usable energy

Human Waste (Problem) → Usable Energy (Resource)

Current Technology: digestion, gasification, pyrolysis
- Disadvantages: long waits, dilution, drying operations

Importance: New, efficient energy conversion technology can address numerous global issues including 1) fossil fuel scarcity, 2) clean water shortage, 3) food safety, 4) disease control, and 5) life-saving energy-production in developing countries

Introduction

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

- *Biosludge:* processed human waste sludge
- *Boiler:* energy harvesting equipment
- *Atomization:* breakup of bulk fluid into smaller droplets - 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

Difficulty: viscosity (thickness) of biosludge varies widely
- High viscosity → large pressure drop restricts flow → poor atomization quality

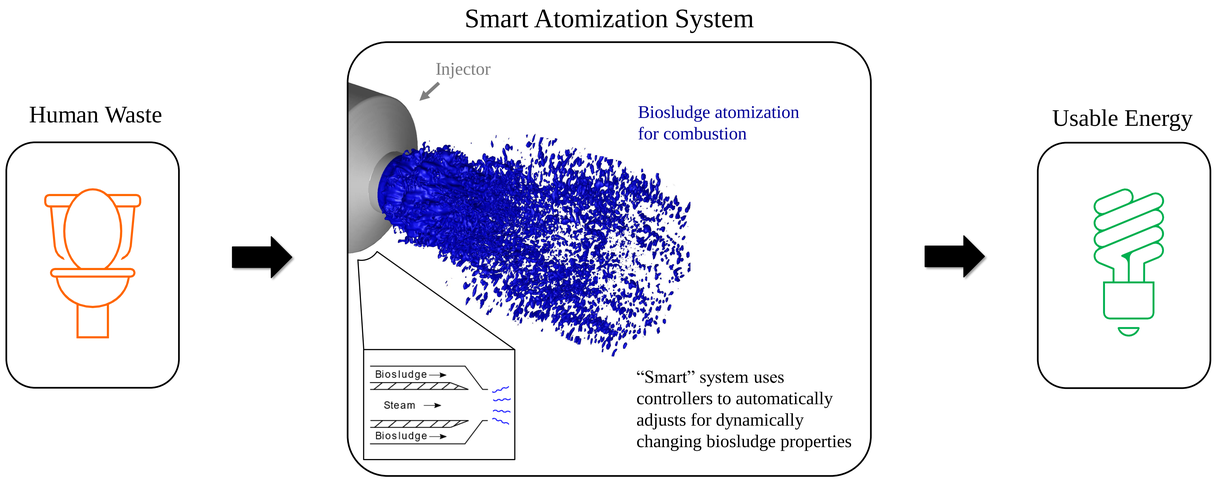
Smart Atomization: adjust flows to account for dynamically changing fluid properties with 2 proportional integral derivative (PID) controllers

Methods

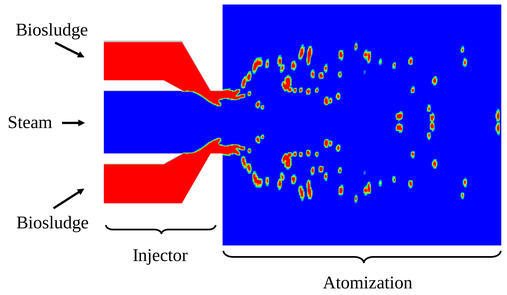
CFD Model:
1. For initial controller tests
- Coarse mesh (resolution) for proof-of-concept
2. For further study
- Fine mesh (resolution) for more realistic atomization

Two 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 SMD (droplet size)
- Objective: maintain atomization quality for varying viscosity

CFD = Computational Fluid Dynamics
SMD = Sauter Mean Diameter (representative droplet size)



Initial tests demonstrate efficacy of coupled controller system



	Ratio of Means		Ratio of Standard Deviations	
Case	SMD	Pressure	SMD	Pressure
C0	1.4	2.5	5.5	1.8
C1	1.2	1.0	6.2	0.9
C2	1.0	4.2	1.5	6.3
C12	1.0	1.0	1.8	0.9

Table 1. *Descriptive statistics for SMD (droplet size) in Figure 1 presented as the ratio of a value **after** the 100x biosludge viscosity change to that **before** the viscosity change (1 = best).*

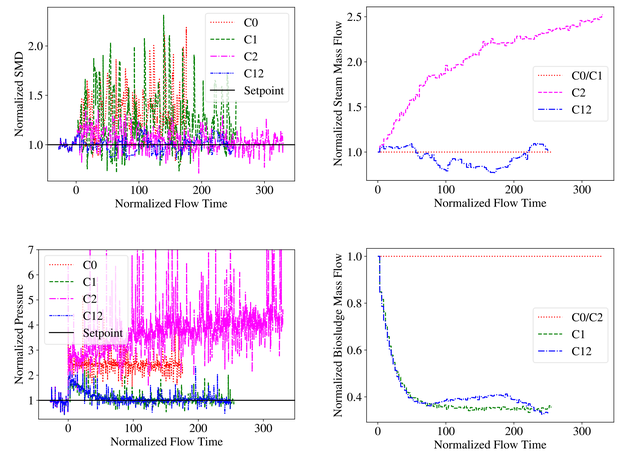


Figure 1. *Pressure and SMD controller responses to a 100-fold increase in biosludge viscosity at time = 0 demonstrating 1) the efficacy of the coupled controller system and 2) the need for **both** C1 and C2.*

Higher fidelity models elucidate characteristics of atomization system

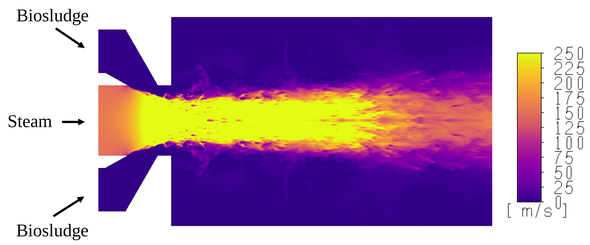


Figure 2. *Contour of velocity for higher fidelity CFD model. The biosludge decreases the exit area for the steam, causing the steam to accelerate as it exits the nozzle.*

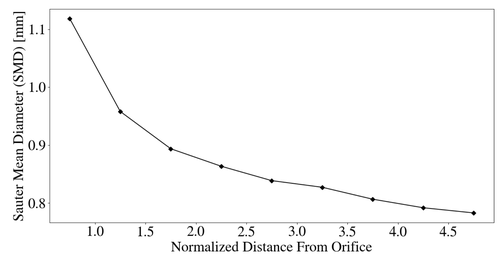


Figure 3. *Axial profile of the biosludge SMD (droplet size) for higher fidelity CFD model. As the biosludge moves through the domain, the average droplet size decreases.*

Results and Conclusions

Controller Tests: controller performance was evaluated for four scenarios across a 100-fold increase in biosludge viscosity (0.05 → 5 kg/m-s at Normalized Flow Time = 0)
- C0 = no controllers
- C1 = only C1 controller
- C2 = only C2 controller
- C12 = C1 + C2 coupled controller system

Pressure Results:
- C0 → pressure increased by 150%
- C2 → pressure increased by 320%
- C1, C12 → flow adjusts, pressure returned to setpoint

SMD (Droplet Size) Results:
- C0 → SMD increased by 40%
- C1 → SMD increased by 20%
- C2, C12 → flow adjusts, SMD returned to setpoint

Conclusions:
1. Coupled controller system *alone* maintains relatively constant atomization quality and biosludge pressure for 100-fold increase in biosludge viscosity
2. We thus demonstrate 1) the efficacy of the coupled controller system and 2) the need for *both* C1 and C2.

Christian Worldview

1. **Exploration** → Discovering the beauty and complexity in God's world
2. **Stewardship** → Use resources for helpful, constructive purposes
3. **Flourishing** → Cleaner, safer world with life-saving resources

Future Work

Proof-of-Concept → Accurate, Efficient Biosludge Atomizer CFD Model
1. Determine if droplet size standard deviation is a better controller measure than the mean droplet size
2. Add variable nozzle geometry
3. Validate CFD results with experiments

References

1. Liu, Z., Carroll, Z.S., Long, S.C., Roa-Espinosa, A., Runge, T., "Centrifuge separation effect on bacterial indicator reduction in dairy manure," *Journal of Environmental Management*, 191, pp. 268-274, (2017).
2. Strasser, W., Battaglia, F., "The Effects of Prefilming Length and Feed Rate on Compressible Flow in a Self-Pulsating Injector," *Atomization and Sprays*, 27(11), pp. 929-947, (2017).
3. Strasser, W., "Towards Atomization for Green Energy: Viscous Slurry Core Disruption By Feed Inversion," *Atomization and Sprays*, (2020). (Accepted for Publication)
4. Wong, S., Zhou, W., Hua, J., "Designing process controller for a continuous bread baking process based on CFD modelling," *Journal of Food Engineering*, 81, pp. 523-534, (2007).