Computational Fluid Dynamics Analysis of Viscous Heating of Feces

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Objective – Use Computational Fluid Dynamics (CFD) to assist with equipment analysis and design if viscous heating to pasteurize fecal sludge.

- Consider an appropriate Viscosity Model

- Examine alternative system geometries to obtain system operating conditions given required flowrates and inlet sludge properties.

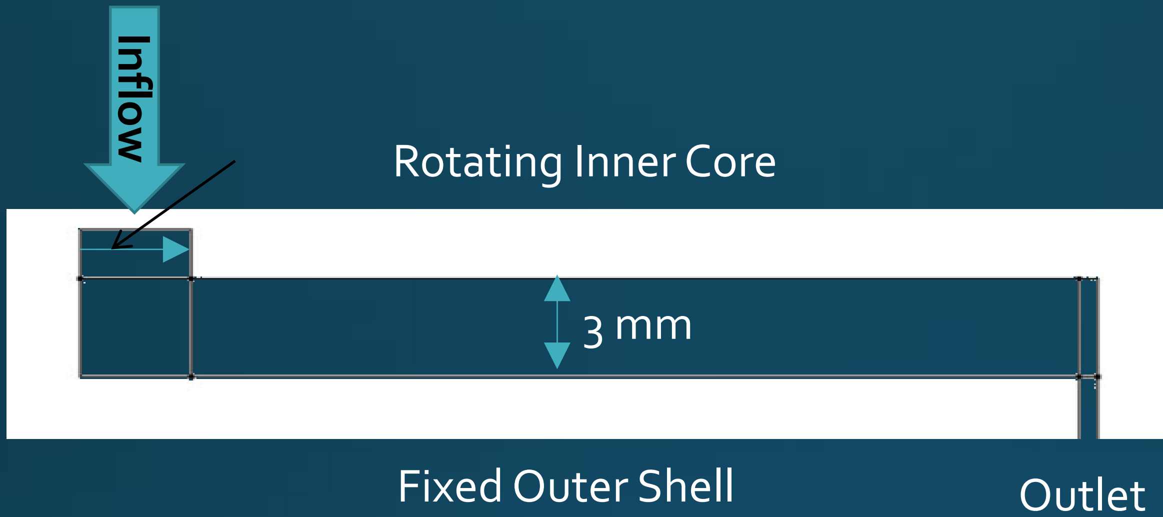
Geometry

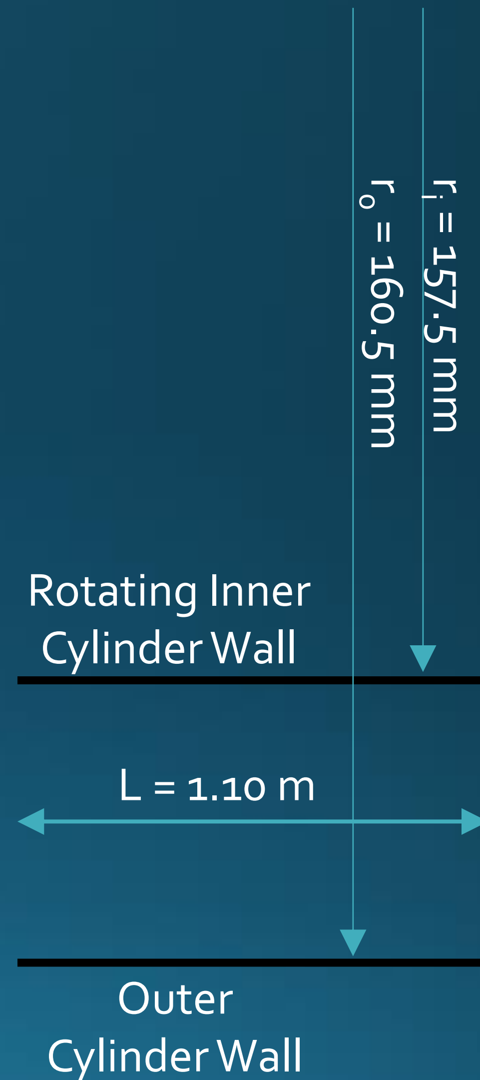
Generate the conceptual CFD, consider alternative operational parameters and build the viscous heater in order to evaluate the accuracy of the model. Once a system is well understood the CFD and equipment should match performance within reasonable bounds.

Built Viscous Heater

Simulated Viscous Heater

Geometric Dimensions





The annular flow path in the gap between the rotating core and fixed outer shell.

Simulation Requires a Viscosity Model

- The Hershel-Bulkley equation has been shown to match the shear thinning characteristics of fecal sludge within the peer-reviewed literature.

- Depending on the CFD software utilized the choices of models may be limited. In this case, the closest reasonable model within COMSOL is the Sisko equation.

- Both are two-parameter, shear thinning expressions where constants are extracted from laboratory data.

"The 38 L/hr" Viscous Heater Operating Data

Viscous heater energy balance with mash potato at three solid contents. Operating conditions were: rotor speed of 1400 rpm, throughput 17.3 kg/h. Gap = 1.25 mm

Solids [%]	Power [W]	Temperature [°C]	Energy Efficiency [%]
10	1 500	70	60
12.5	1 800	90	73
15	2 200	101	72

Viscosity Characterization: The Sisko Equation

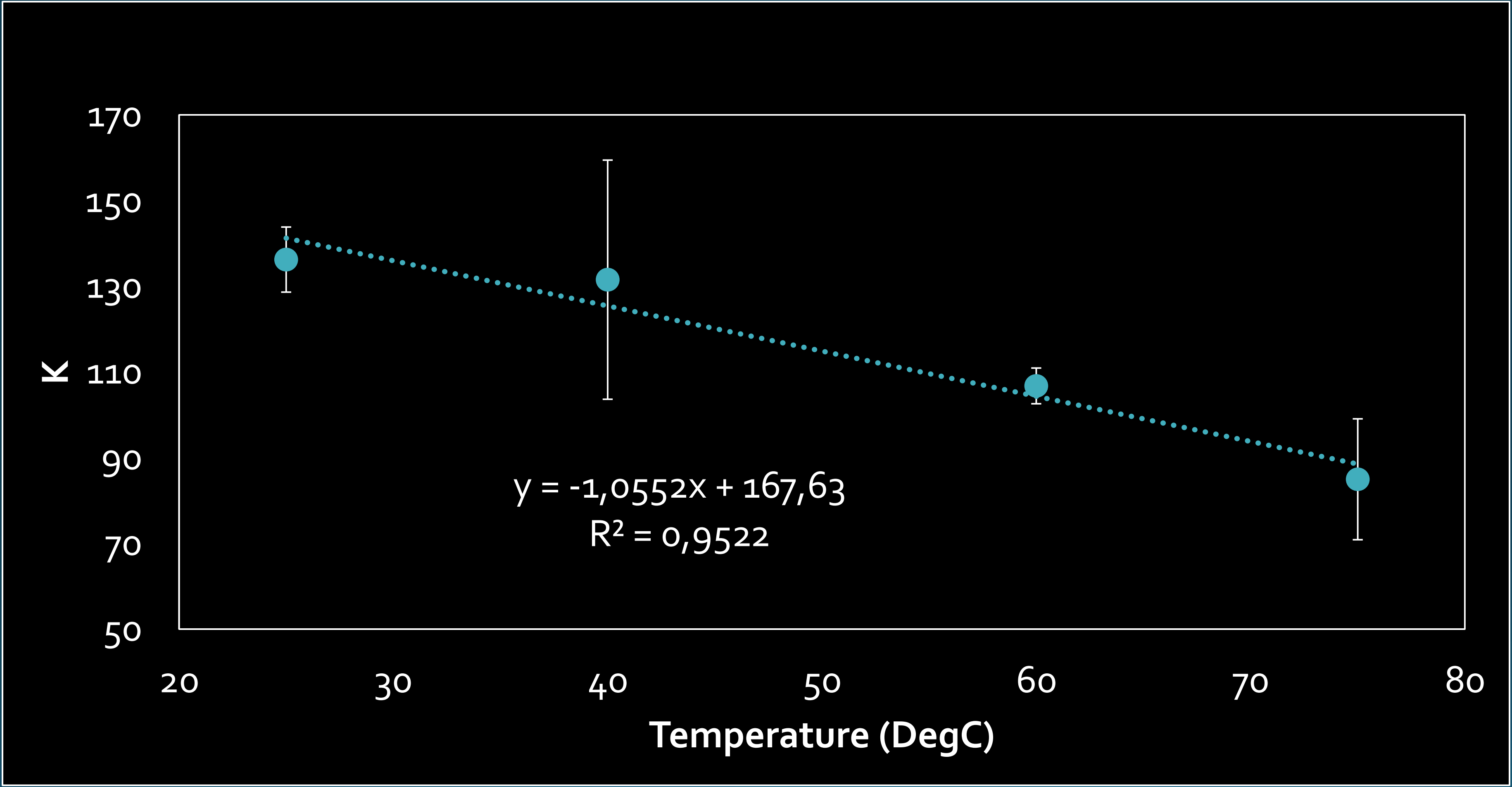
$$\eta(\mathbf{Pa}\cdot \mathbf{s}) = \eta_{\infty} + \mathbf{K} * \gamma^{\mathbf{n}-\mathbf{1}}$$

Effect of Temperature on Sisko Equation Variables K and n

T (°C)	K	std dev	n	std dev
25	136	8	0.36	0.003
40	132	28	0.38	0.03
60	107	4	0.32	0.02
75	85	14	0.36	0.01
	Average K		Average n	
	115		0.35	

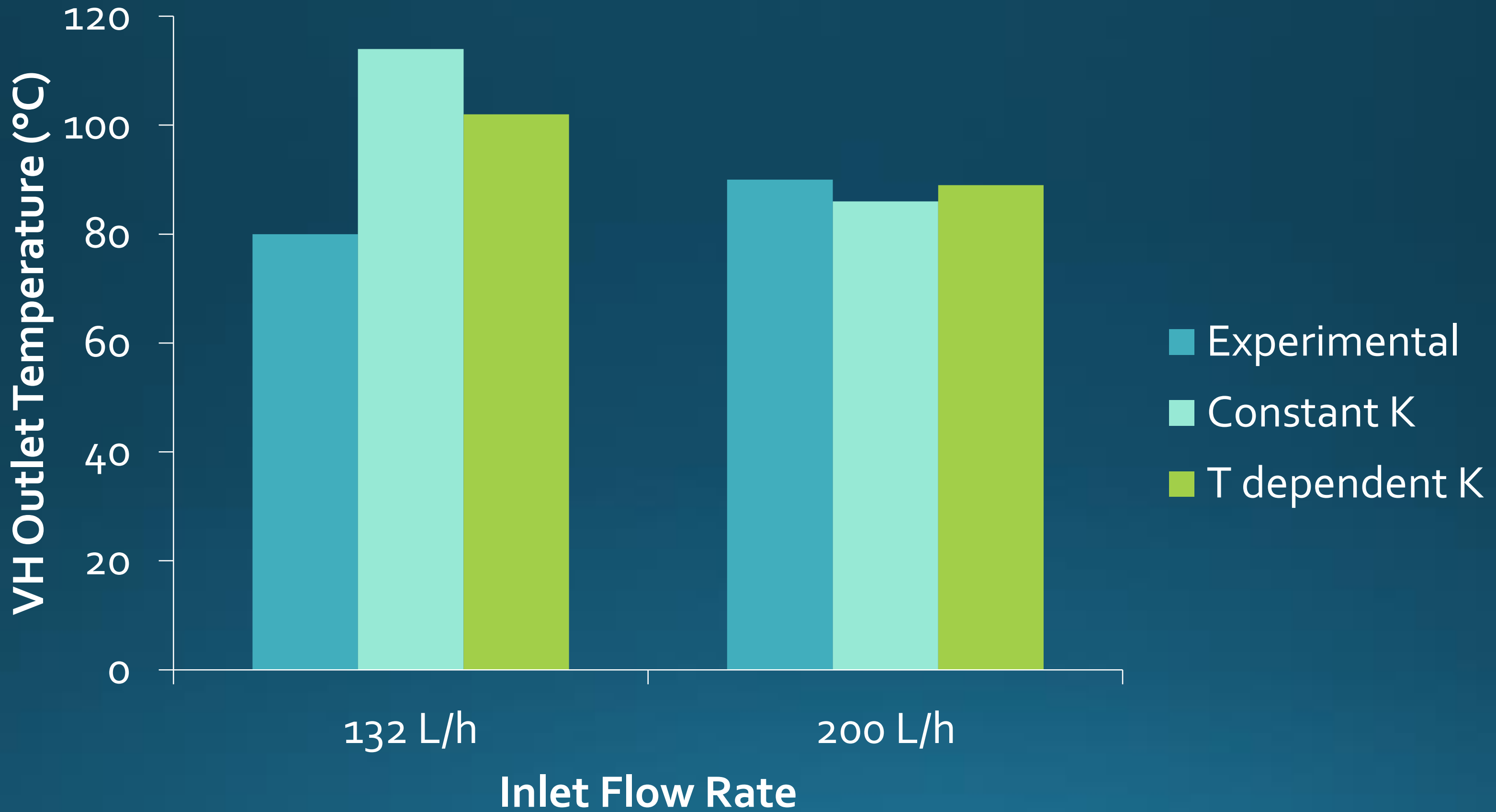
Obtained from rheometer experiments using potato paste with 12.5% solids

K Dependency on Temperature



$$\eta = \eta_{\infty} + (-1.0552 * T + 167.63) * \gamma^{n-1}$$

Effect of K on Viscous Heater Outlet Temperature



*Rotational speed was changed from 700 rpm to 800 rpm for the 200 L/h set

Comparison of viscosity model with Simulation

Average Annular Viscosity (Pa·s)				
	Viscous heater model		COMSOL	
Flow (L/h)	Avg K	Temperature Dependent K	Avg K	Temperature Dependent K
132	0.366	0.303	0.364	0.299
200	0.334	0.317	0.334	0.298

- The annular viscosity calculated using the Sisko model matched well with the average annular viscosity from simulation

Validation using Power Requirements

	Thermodynamic model		Viscous heater model		COMSOL	
Flow (L/h)	Avg K	Temperature Dependent K	Avg K	Temperature Dependent K	Avg K	Temperature Dependent K
132	25.2	19.0	18.2	15.1	18.6	13.9
200	19.6	20.5	21.7	20.61	22.1	20.3

Note: Date from the 38 L/hr viscous heater was used to target a 200 L/hr design. When constructed, the larger unit operated at 325 L/hr.

Scale Up Estimation of Power Requirement

Restrictions	**Targets**
• Gap space	0.3 cm
• Length	1.5 m
• Rpm	1400

Design Target is inlet flowrate of 1000 L/h and outlet 80°C

Example Simulation Conditions

Length (m)	Inner Radius (m)	Gap Space (mm)	Average Outlet Temp (°C)	Required Power (kW)
1.5	0.064	3.4	82.4	66.4
1	0.071	3.1	78.5	62.3

Result of Scale-Up

38 L/hr lab-scale viscous heater

325 L/hr scaled viscous heater

Conclusions

- CFD is a useful tool for design analysis once appropriate property data has been collected.
- CFD allows for multiple, alternative simulations without the high cost of construction trial and error.
- As more data are collected the accuracy of the CFD model is improved and design options become more realistic.

- 1000 L/hr viscous heater results pending….