Auger-Die Assembly to Treat Fecal Waste
Phase 1 Final Report
December 15, 2012

1. Activities

During Phase 1 we have confirmed that viscous heating and shear stress created in an Auger/extruder assembly can sanitize human waste. We designed, built and operated a mechanical extruder that achieves near 200°C effluent for a fecal simulant and destroys 99% of parasite worm eggs near ambient temperatures.

Design began with Computational Fluid Mechanics (CFD) analysis of several equipment geometries. Temperature and pressure profiles were generated for numerous operating conditions that would indicate the likelihood of conditions sufficient to kill disease-causing microorganisms. A prototype was constructed from this CFD design and instrumented to obtain a wide range of performance data.

An appropriate fecal simulant was selected from a literature review. Materials with similar viscosity and moisture content to that of human feces were shortlisted. Flour and several types of boiled potatoes were then tested in a rheometer (Bohlin Instruments, Model CVOR 200). Experimental results were plotted along with literature for several fecal materials. Figure 1 presents our viscosity data for these starchy materials in comparison with pig caecal, chicken caecal, and human stool. From these data, red potatoes were selected as the simulant to be used for our preliminary evaluation of the equipment.

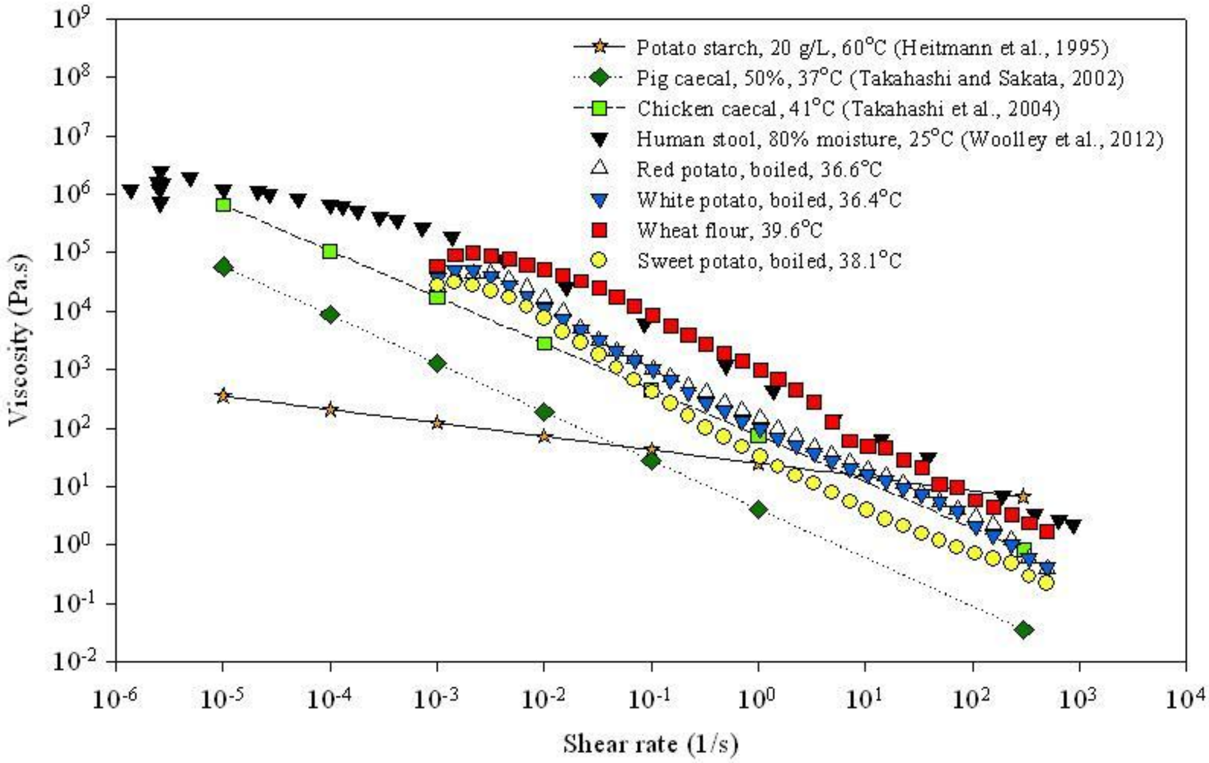

Figure 1. Shear rate decrease with viscosity for various feces and simulants

The first generation of the experimental equipment is shown in Figure 2. The design was aimed on the acquisition of experimental data. Actual fecal sanitation equipment would be significantly different. The actual extruder/reactor component is the horizontal conical section located in the center of the photo. The extruder is a fixed shell with a rotating inner core driven by the motor on the bottom right. The machine operates with a variable feed pressure (0-100 psig) seen on the bottom left for flow rate control. The pressure is regulated by an air line and observed with the pressure gauge. The spacing (0.75-1.25mm) between the rotating inner core and the fixed outer shell is variable in order to evaluate the gap geometry. The mass flows through this gap with the inner cylinder rotation at a speed between 0 to 1700 rotations per minute (rpm). Temperature is recorded by a thermocouple (Omega HHM 31 Digital Multimeter) placed at the mass flow outlet.

Figure 2. Instrumented reactor to process fecal and simulant solids

The plunger in Figure 3 moves inside a cylindrical feed chamber to press the feed inside the shell. A hole on the cylindrical chamber allows the operator to charge the feed material for any specific experiment. The plunger is air driven and can push the feed with a gauge pressure from 0 to 100 psi. On the right side of Figure 3 the motor is connected to a Hitachi WJ200 Series 200 V three-phase inverter which sets the required rpm in the AC motor.

During experimentation, as the core rotates within the shell potatoes flow between the two metallic surfaces. Initially, after the spacing is filled, the outlet is closed for a time to allow the potatoes to achieve a steady state operating temperature. The maximum temperature observed for a given material is a function of spacing and rpm. Temperature of the simulant or feces increases by viscous heating only with no other energy input. When mass is allowed to exit the reactor, the effluent temperature observed at the outlet reduces somewhat since fresh mass is now entering the reactor at room temperate; however, the effluent temperature can be controlled by flow rate, gap spacing and rpm. Overall, as the time within the gap increases so does the measured effluent temperature.
Once the mass leaves the extruder its temperature decreases rapidly due to evaporative cooling. Within the react moisture is trapped by the geometry, but when the hot mass is

reduced to atmospheric temperature this water begins to vaporize and the associated heat of vaporization cools the remaining solids. We believe this water can be reclaimed leaving a dried solid.

Some of the experimental results of observed temperature are presented in Figure 3. For the initial warmup, temperature increases with the holdup time. A temperature of 190°C was obtained at 260 seconds hold up time. Conditions in Figure 3 are a feed pressure of 100 psig, 1700 rpm and 0.75 mm gap spacing. These results suggest that mass flow rate can begin after four minutes. We performed additional experiments – not presented – over a broad range of constant rpm and spacing and found similar trends. For experiments where mass flow was initiated after achieving the desired temperature the flow could be as high as 250 g/min and maintain 120°C.

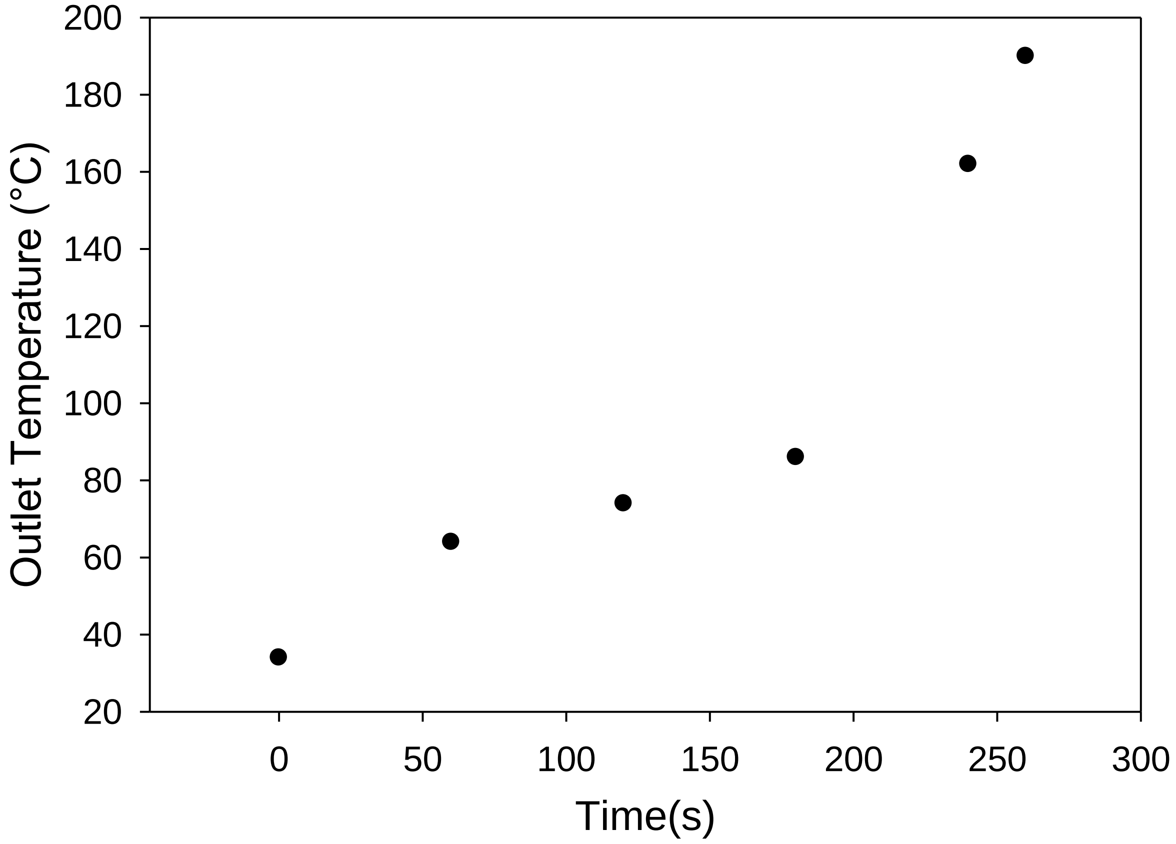

Figure 4. Temperature with time at constant 100 psig, 1700 rpm and 0.75mm spacing

Over a wide range of operating conditions the following observations were made. Temperature rises with decreased spacing. No maximum was observed, so there is a likelihood that spacing less than 0.75 mm will generate even higher temperature. The effluent mass was observed to be hot and moist and dried quickly in open air. Increasing rpm gave higher temperature. As the viscosity of the mass fed decreases so does the observed outlet temperature. For each experiment, fixing two variables from among rpm, holdup time, and gap spacing allowed one variable to be compared with the resulting temperature change. Temperature was observed to increase with decreasing gap distance, increasing rpm and increasing contact time. Shear force and viscous heat are sufficient to kill diseases causing microorganisms.

These results tell us several key facts. We can generate more heat than required to sanitize the waste, which allows for operating conditions to be more mid range resulting in less wear and tear on equipment. Spacing is small, indicating that debris must be removed from fecal mass prior to being fed to the extruder. Viscosity must be sufficient for heat to be generated; normal stool has a viscosity near 5000 centipoises and this is sufficient. However, for less viscous (diarrheal) or diluted (urine or water influent) then increasing viscosity must be part of the design. We believe that recycle is a logical method to address the latter.

Additional experimentation took advantage of the fact that Oklahoma State University is the home of the National Center for Veterinary Parasitology. We used a Biosafety Level 2 (BSL-2) laboratory to perform tests on baboon feces using the equipment. The feces were infected with *Trichuris trichiura* eggs – a parasitic worm. The parasite loading levels were quantified by observation under microscope for both influent and effluent samples. Temperature data were obtained with a thermocouple. The egg destruction is shown in Table 1. The rpm shown is correlated with power input to the inverter by calibration; however, the speed presented may be lower due to a considerable amount of hair present in samples – typical for baboon feces due to their grooming habits. This affects the ability to achieve the high temperatures observed with potatoes.

Table 1. Percentage parasite egg destruction with variable settings

rpm	Spacing	Temperature	Pretreatment	Post Treatment	Percentage kill
	mm	°C	EPG	EPG	%
875	1.20	42	107.1	7.7	93
1700	0.75	51	166.5	1.7	99
1700	0.75	86	58.0	2.8	95

*Trichuris trichiura Eggs per Gram of baboon feces

Despite the low temperatures observed, egg destruction approaching 99%. This result indicates the significance of the additional shear stress mechanism. In addition, we may not have operated efficiently due to a limited amount of available infected sample. We believe that complete disinfection would occur, regardless of shear stress, if the effluent temperature can be established and controlled to 120°C.

2. Challenges

Maintaining sufficient feed viscosity will be a requirement of effective operation. We have tested a mixture of grass with potato simulant as feed material for the current equipment. This does allow observed temperatures greater than using simulant alone. We also believe that other biomass, such as saw dust and paper, could be used to increase the viscosity of the feed mixture.

For cases where people have diarrhea, where urine is not separated or when water is added by rain or other means, this technology will require a modified design. As part of a Phase 2 project we will propose equipment modifications that take full advantage of generated heat to evaporate and recover water in fecal solids; which, in turn, will allow some of the processed solids to be recycled back into the feed stream for viscosity control. By balancing the ratio of recycle to fresh feed, the required viscosity can always be achieved. Even with all water feed and high recycle, viscous heating can be sufficient to vaporize the water for sanitized condensation.

Another challenge is to reduce the energy consumption to rotate the inner core. This will be addressed by considering different geometries or construction materials focusing on heat transfer properties and rotational momentum. Currently, we are evaluating calculations of theoretical power required using different geometries. Our goal is to find the optimized power requirement to operate the equipment.

A significant challenge is to separate debris such as gravel, bottle caps, coins, cloth and other trash that would block or bind the mechanics. This will require screening or segregation. As such, this technology, while highly effective for controlled feed streams, will require integration with associated technologies in practical settings. However, its use within an integrated system will result in sanitation of fecal waste for safe handling, subsequent processing or transportation. Sanitized solids could potentially be used as nutrient material in agricultural applications. It may also retain some energy for thermal or bioconversion processes. Evaporated water recovered from the process would be sanitized for safe use in non-potable applications, but would require further treatment to be consumable.