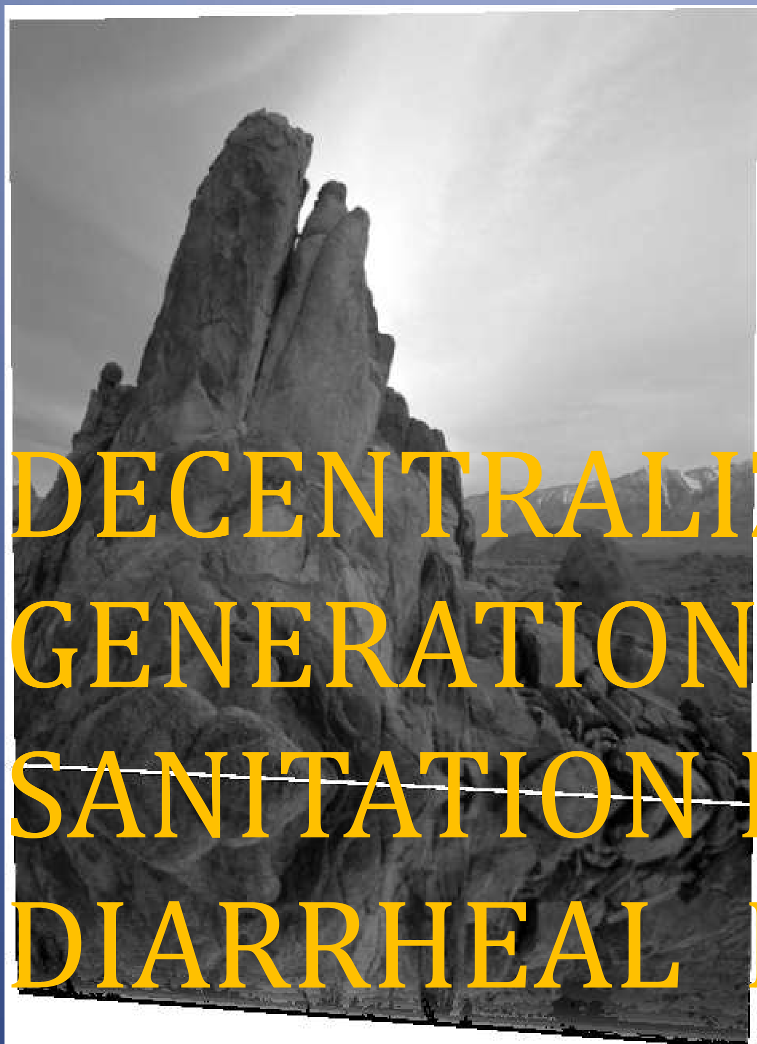

DECENTRALIZED NEXT GENERATION SANITATION FOR DIARRHEAL PATHOGENS

Grand Challenges Exploration OPP1033277

on; Water, Sanitation and Hygiene Group

dergraduate and graduate students, some supported by
of people along the way. Thanks to them all.

DECENTRALIZED NEXT GENERATION SANITATION FOR DIARRHEAL PATHOGENS
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Sponsored by the Bill and Melinda Gates Foundation; Water, Sanitation and Hygiene Group

A final report to develop the Windmill-Driven ATAD

for use in underdeveloped countries.

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The Vision….

…. The Reality

Supported by the Bill and Melinda Gates Foundation, Grand Challenges Exploration 6

This is a final report on the Bill and Melinda grant entitled: Decentralized Next Generation Sanitation for Diarrheal Pathogens. It was funded by the Foundation's grant, some critical funding by the Department of Mechanical Engineering and Energy Processes and a load of enthusiastic students. Critical non-obvious findings change our viewpoint of what happens as the wind stops blowing. A critical finding and invention also was made by Senior Students in their ME 495 Senior Design Project. There were many people which helped all along the way.

The overarching goal of a decentralized system for 15-20 villagers has been demonstrated on industrial waste with a small amount of sewage-human excreta. The system has been driven by renewable energy and the chemical energy contained in the feed, and has survived maintenance of thermophilic temperatures and residence times needed for pathogen reduction. While we have conclusively shown this for swine waste, this project will expand to application of an industrial waste with low level of in an outside pilot system with varying weather conditions. The objective of this work is to generate maximum pathogen removal for all pathogens present.

This work has been based on a very old idea, energized with new technology. Most people in the world agree that if you can heat the excrement to high enough temperatures, and for long enough, the disease agents will perish and even their more resistant spore, and oocyst, and egg forms will die. This lessens the numbers of pathogens entering the environment and reduces disease. The problem is that the required heat as conventional energy is too expensive for sanitation. Our key problem is finding a very low cost source of energy with which to aerate the semisolid fecal material in a well-insulated system. Even though ideally the ATADs can generate about 6 times the energy it uses but it currently uses high value electricity and generates low value 60°C hot water. Switched to wind energy for aeration, it would almost eliminate operating costs and would be cheap enough for decentralized applications while producing pathogen free products.

Organic material such as human fecal material contains 14.4 Mj of energy/kg of chemical oxygen demand (COD2, a form of the COD test which doesn't use mercury) consumed. This is released as heat as the microorganisms degrade it to biomass and ultimately carbon dioxide. Being a wet system, the heat is used in several ways: 1) to heat up fresh excreta to the system temperature, to vaporize water in the waste and carry it out with the exhausted air, being lost to the walls and outside environment of the system, and most importantly to maintain the waste temperature at a thermophilic level. In a well-insulated system with a COD2 feed concentration typical of human excrement of developing countries, and the right amount of air fed, about 0.5 kW of heat would remain after the other heat losses. This will be enough to maintain the waste temperature in the thermophilic ranges (40-60°C). The other part of the equation depends on how long one holds the waste at these temperatures.

In past work we have done with fresh swine waste, we have experienced 10,000 to 1-millionfold reductions of pathogens like *Campylobacter jejuni*, *Salmonella enteriditis, Escherichia coli*, *Staphylococcus aureus*, *Enterococcus fecalis* and *Clostridium perfringens* in periods between a few hours and 6 days. In this work we choose not to add pathogens for two reasons: first, as an outside experiment, it might be implicated in disease for the community. The second was discovered when I managed a long term (~10 year) project on ATADS for swine odor reduction. Then we measured the actual organisms in the swine waste. In work we have done with fresh swine waste, we have experienced 10,000 to 1-millionfold reductions of pathogens like *Campylobacter jejuni*, *Salmonella enteriditis, Escherichia coli*, *Staphylococcus aureus*, *Enterococcus fecalis* and *Clostridium perfringens.* All gave excellent, almost remarkable reductions over 6 days at 55 °C

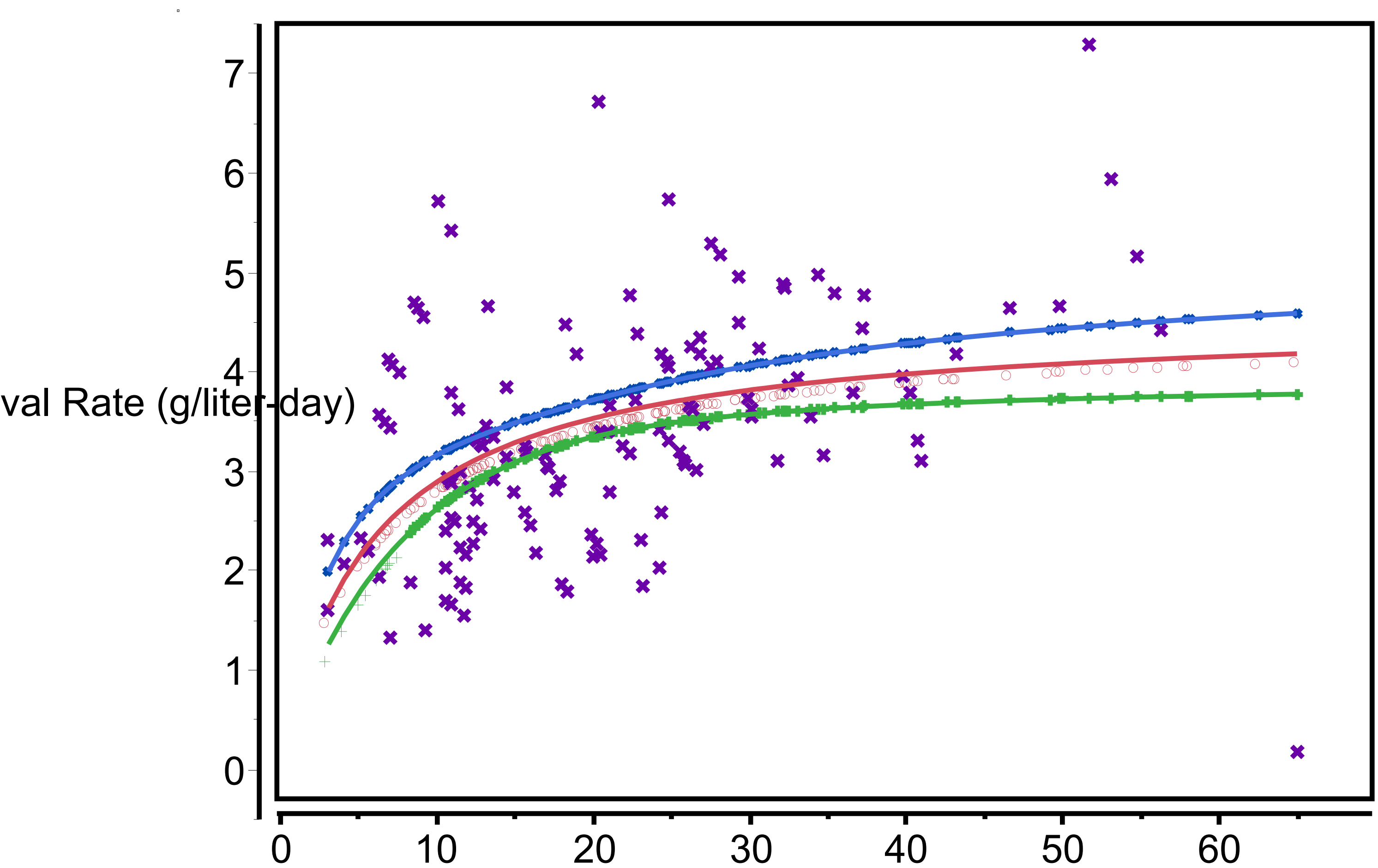

Figure 1. X-axis is in COD2 (g/L), Y-axis is the COD2 Removal Rate (g/(L-D). Michaelis Menten kinetics of COD2 removal proportional to heat generation from **11 large-scale (3 m^3) swine waste runs** with controlled variables, except for feed composition.

Legend
- COD Removal Rate--Michaelis Menten Model, Nonlinear Curve Fit (g/liter-day)
- Upper Model 95% Confidence Limits
- Lower Model 95% Confidence Limits
- Measured COD Removal Rate (g/liter-day)

Since COD removed is proportional to biological heat generation, the kinetics of heat production in our recent BMGF field trial, the results are similar to biological heat production in fresh swine waste. Using wind energy to drive an air blower and varying outside temperature conditions will be certain to provide changing temperatures and aeration conditions in our system, possibly leading to lower disinfection efficiencies. In the proposed study, we will use native fecal coliforms and *E. coli* as the indicator pathogen.

Our first planned activity was to purchase a bellows-style 28 ft commercial windmill we felt would have high reliability. We must create an aeration system driven with renewable energy and being effective over varying weather conditions. Unlike ATADS built with constant and controlled airflow, we knew that we will have a variable wind speed and therefore periods of successful operation and maybe periods of unsuccessful operation. We are unaware of any ATAD system in the world depending on variable wind air flow such as ours at this time. Supplying oxygen with the wind has a major positive impact on economy.

The first key is determined as the windmill speed to air flow delivered. Once we saw the size and travel of the bellows we became concerned that instead of making sufficient air 70% of the time, the windmill could only deliver a fraction of amount of the air and generate air flow 50% of the time. This is perhaps the greatest problem in the system so we calibrated the windmill ourselves. A simple setup, we directly drove the shaft and blower at a range of constant speeds, while the output air was determined by water displacement. Figure 2 presents the efficiency curves the manufacturer gave to us and the values we measured with the water displacement meter.

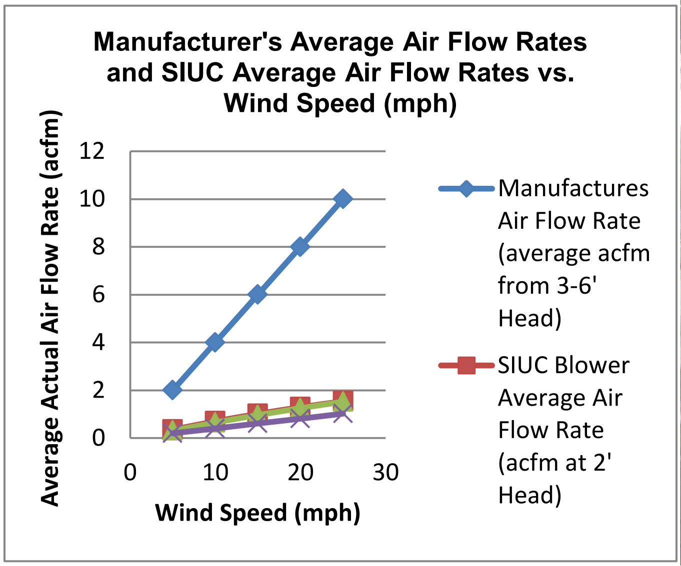

Figure 2. Manufacturer’s Windmill air flow

Figure 3. Water displacement meter.

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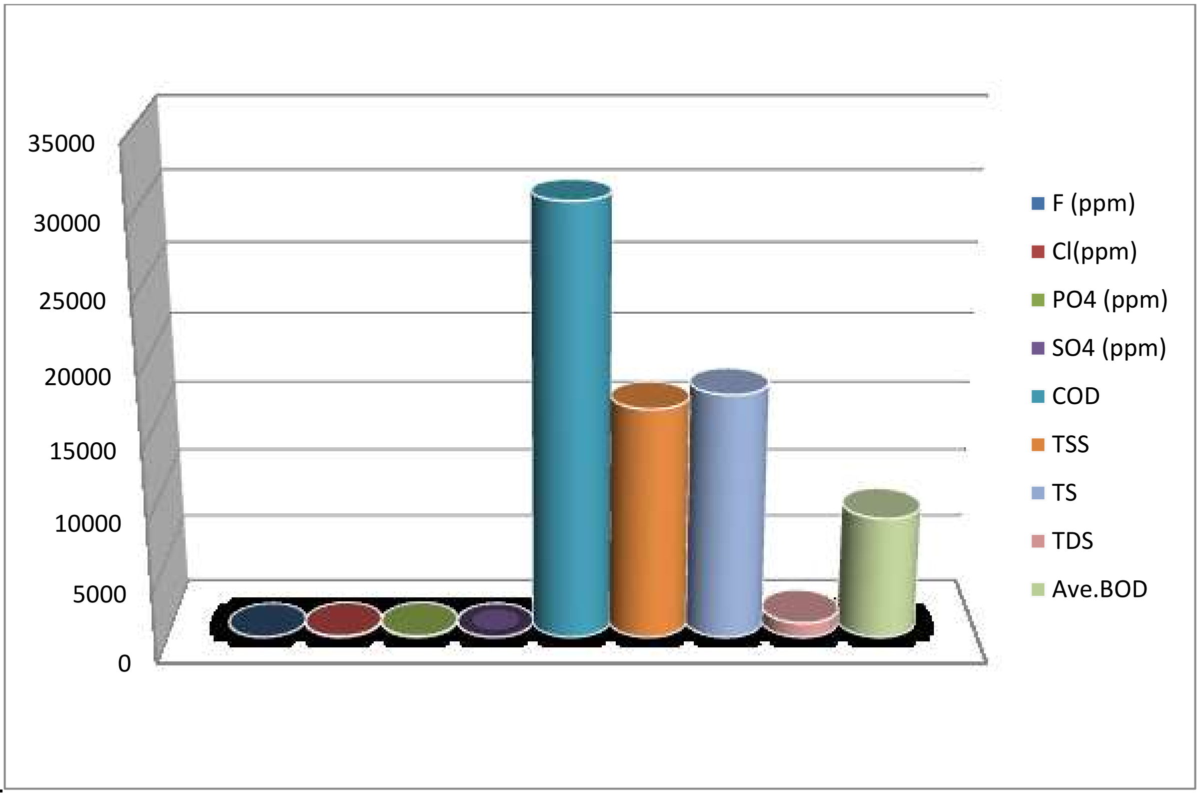


Figure 4. Feed to Run 1 (mg/l)

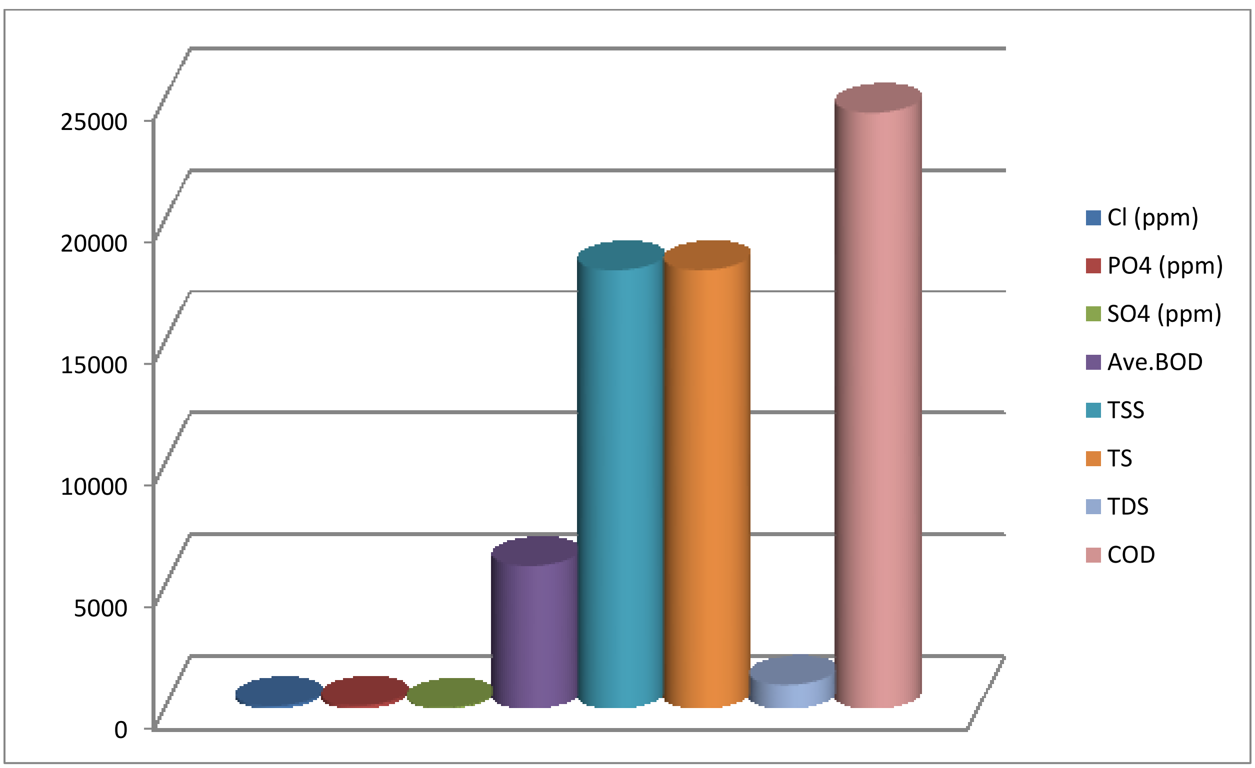


Figure 5. Feed to Run 2 (mg/l)

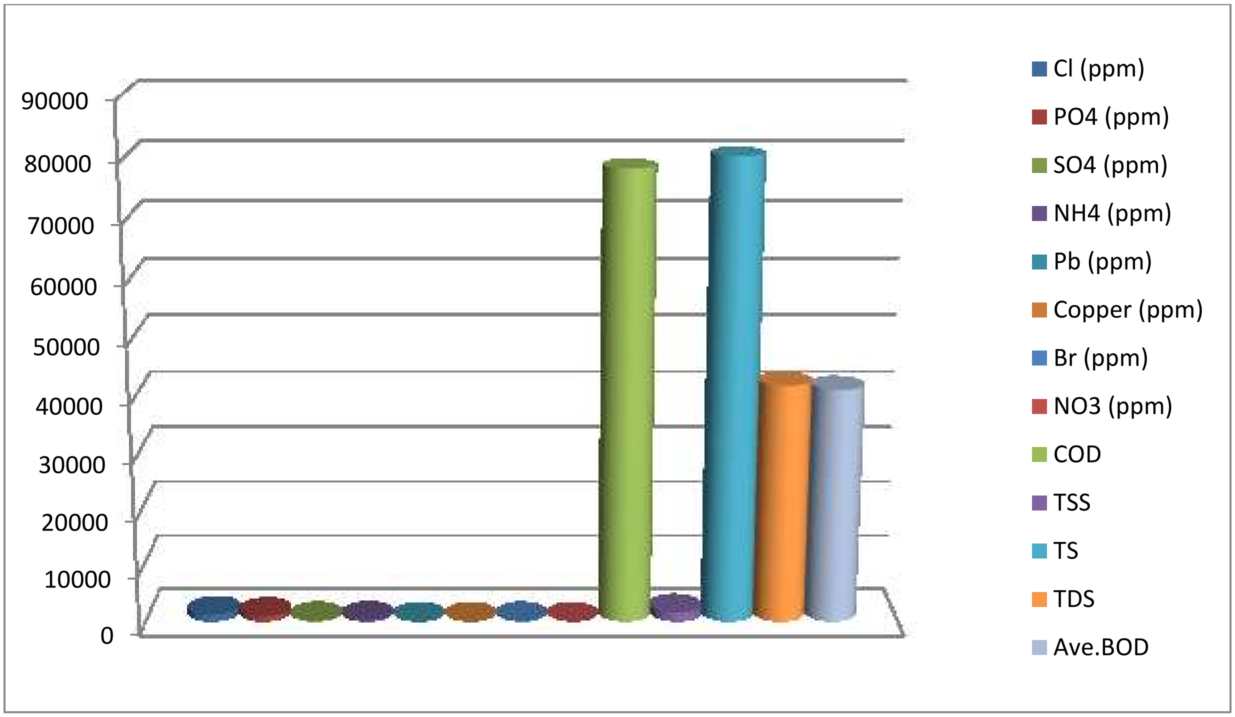


Figure 6. Feed to Run 3 (mg/l)

We had to use a source of COD2 available and then have a disposal method after the experiment (10 gal/day). Only the Northwest Carbondale Treatment plant fit, but their only concentrated stream (higher concentrations may lead to higher heat production) was nearly exclusively industrial waste. Figures 4-6 show respectively the waste (our feed) quality for Gates Runs 1-3.

In the second and third analysis, the BOD5 (Biochemical oxygen at 5 days) divided by the COD2 is about 0.25 and 0.5 respectively. The significance is that only the fraction representing BOD5 can be degraded in acceptable residence times. This stream is only indicative for extrapolation to the behavior of warm human excreta.

Also working against us was the standard seasonal reduction of wind during January to June in Carbondale.

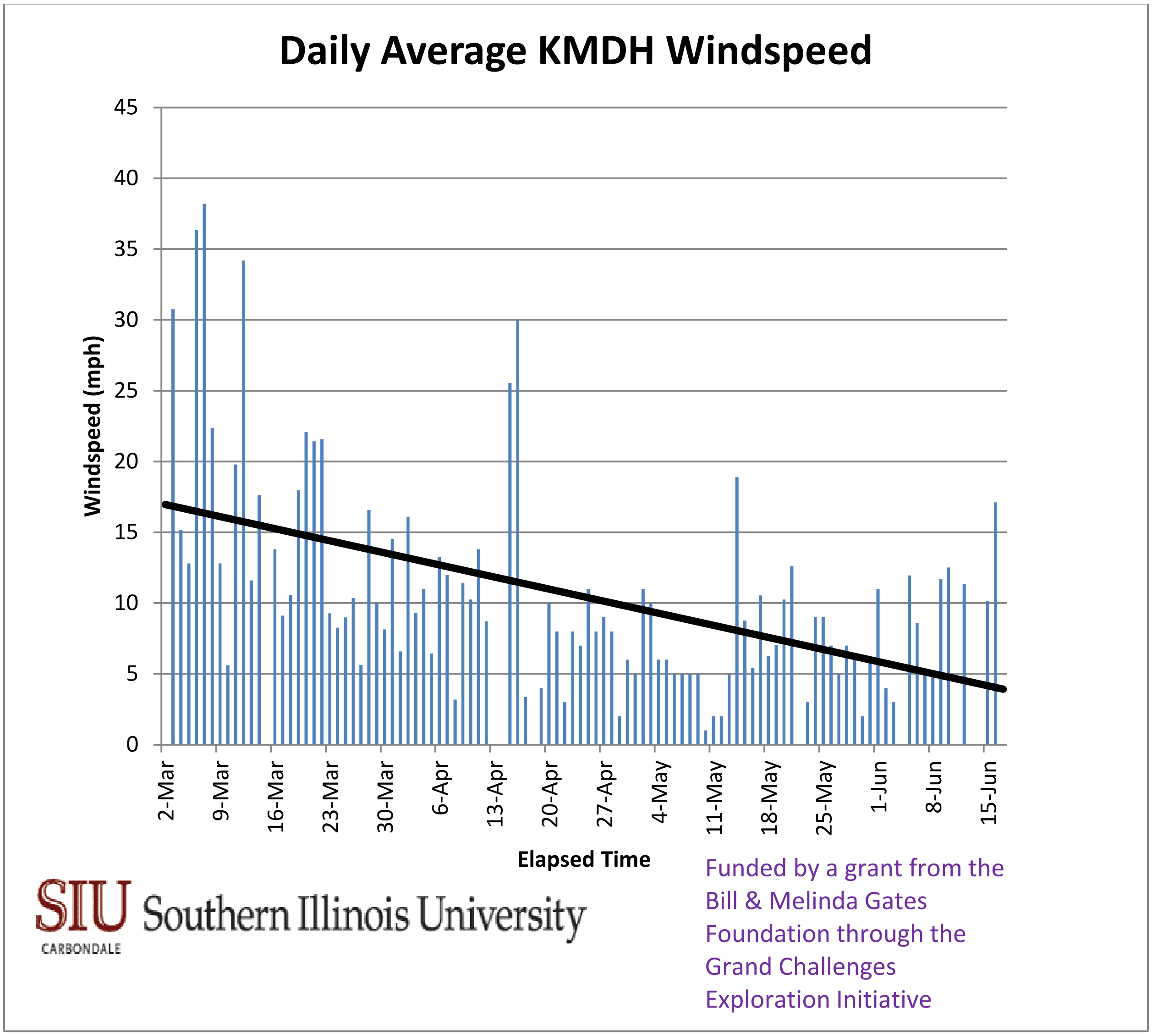


Figure 7. Seasonal drop in (KMDH) windspeed

Figure 7. shows clearly the natural decline in windspeed as taken from the KMDH (international call sign) – Airport with METAR continuous readings for aviators. Being only 2 mi from the WWTP and testing how the anemometer at the airport and windmill shaft speed correlate with the KMDH data (available each hour), we were very confident that we could use METAR data to correlate our measured shaft speed (we mounted a wireless transmitting tachometer on the wind shaft and this led to excellent data). These data represent a decline in biological heat production “when the wind has a downward trend.”

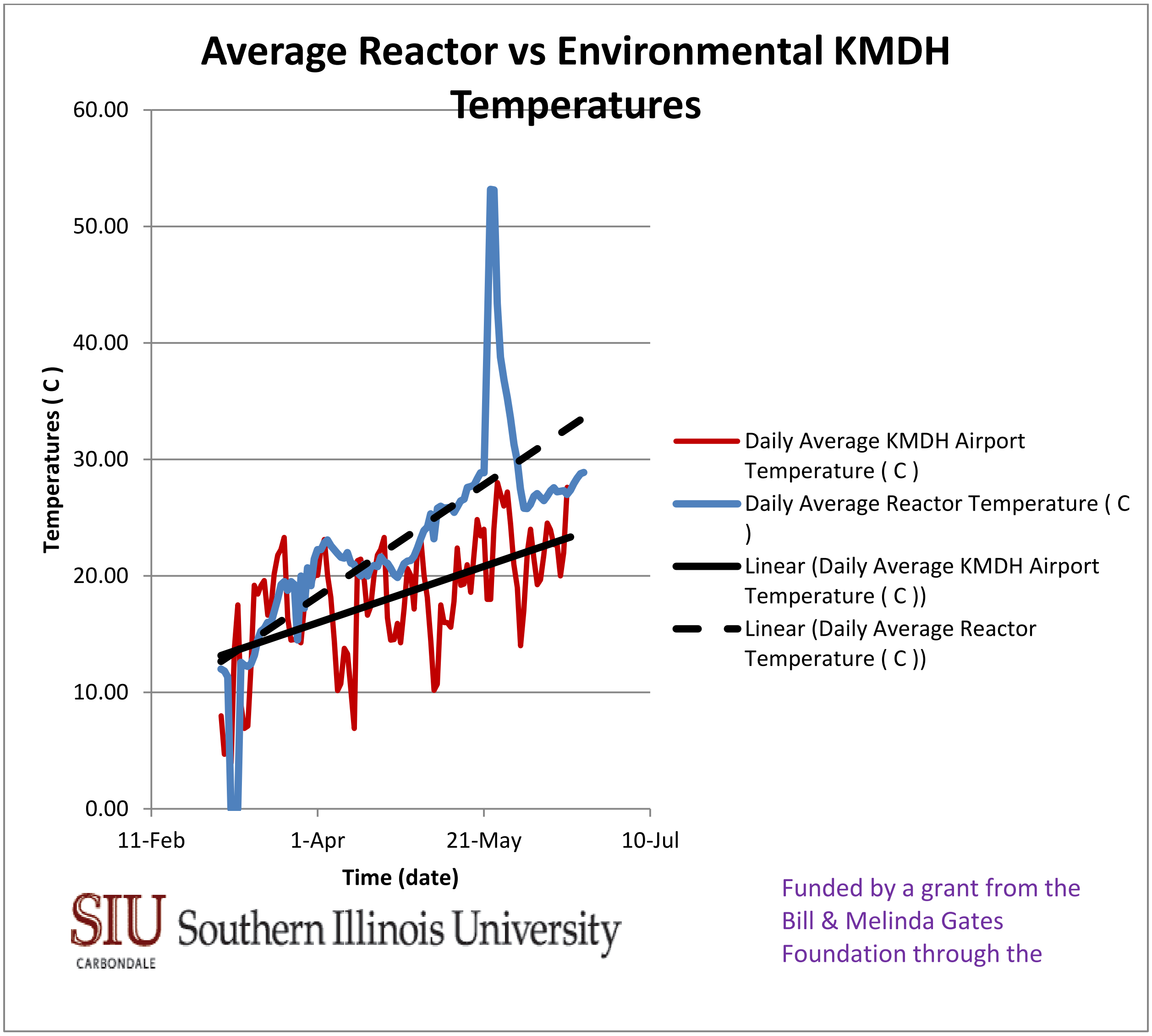


Figure 8. Shows the 24-hour average for both the ambient temperature and the reactor- 4 averaged and calibrated thermocouples.

Please note that the blue line is nearly always on top of the red line signifying a heating process is ongoing virtually at all times. This has to be from the organisms in the reactor, even with all the negatives like loss of wind over this time frame. We added the pulse in the blue line to test the system at high temperatures and to make sure the thermophiles were still present. We spiked live steam into the reactor until the reactor temperature was over 70° C.

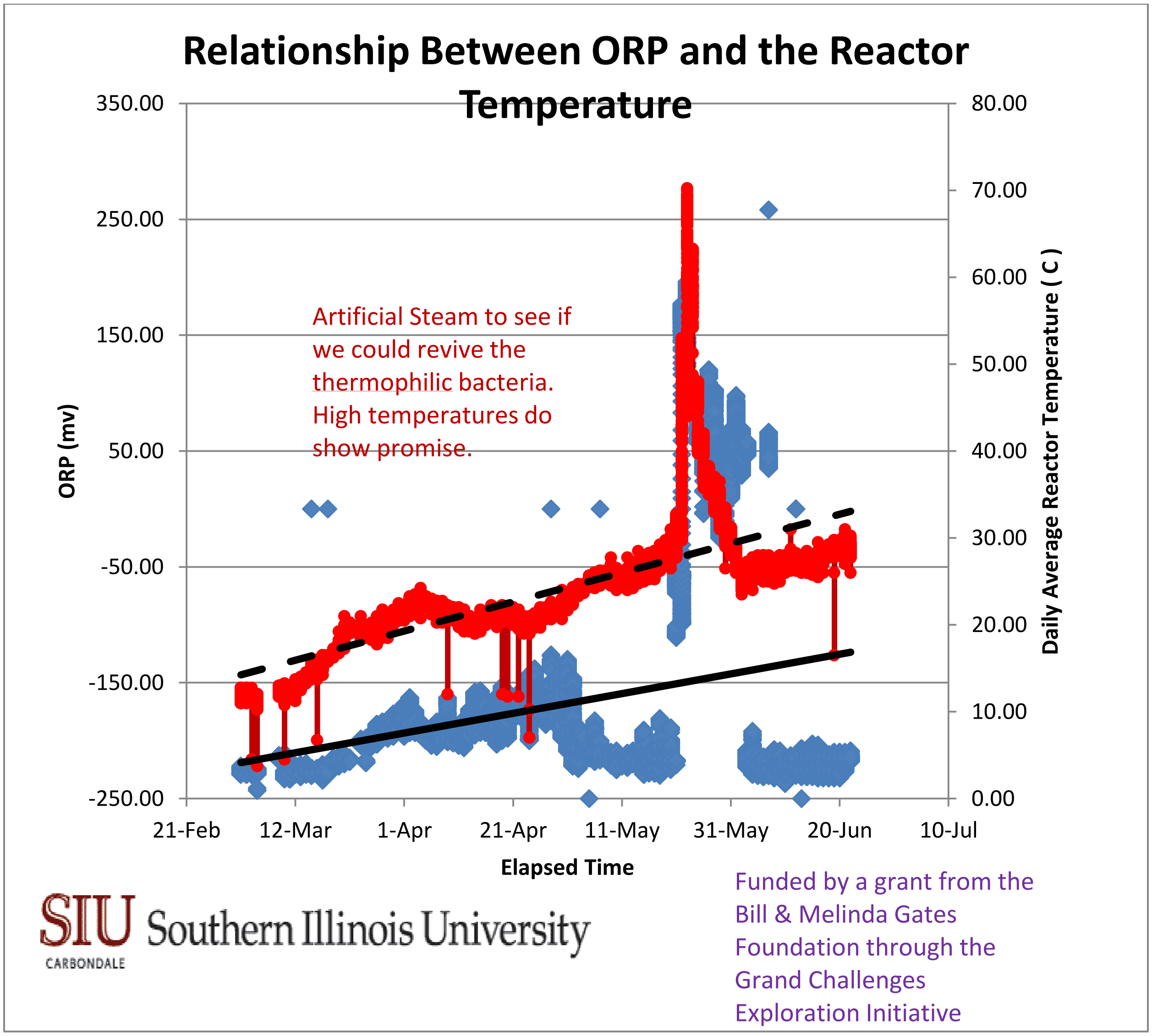
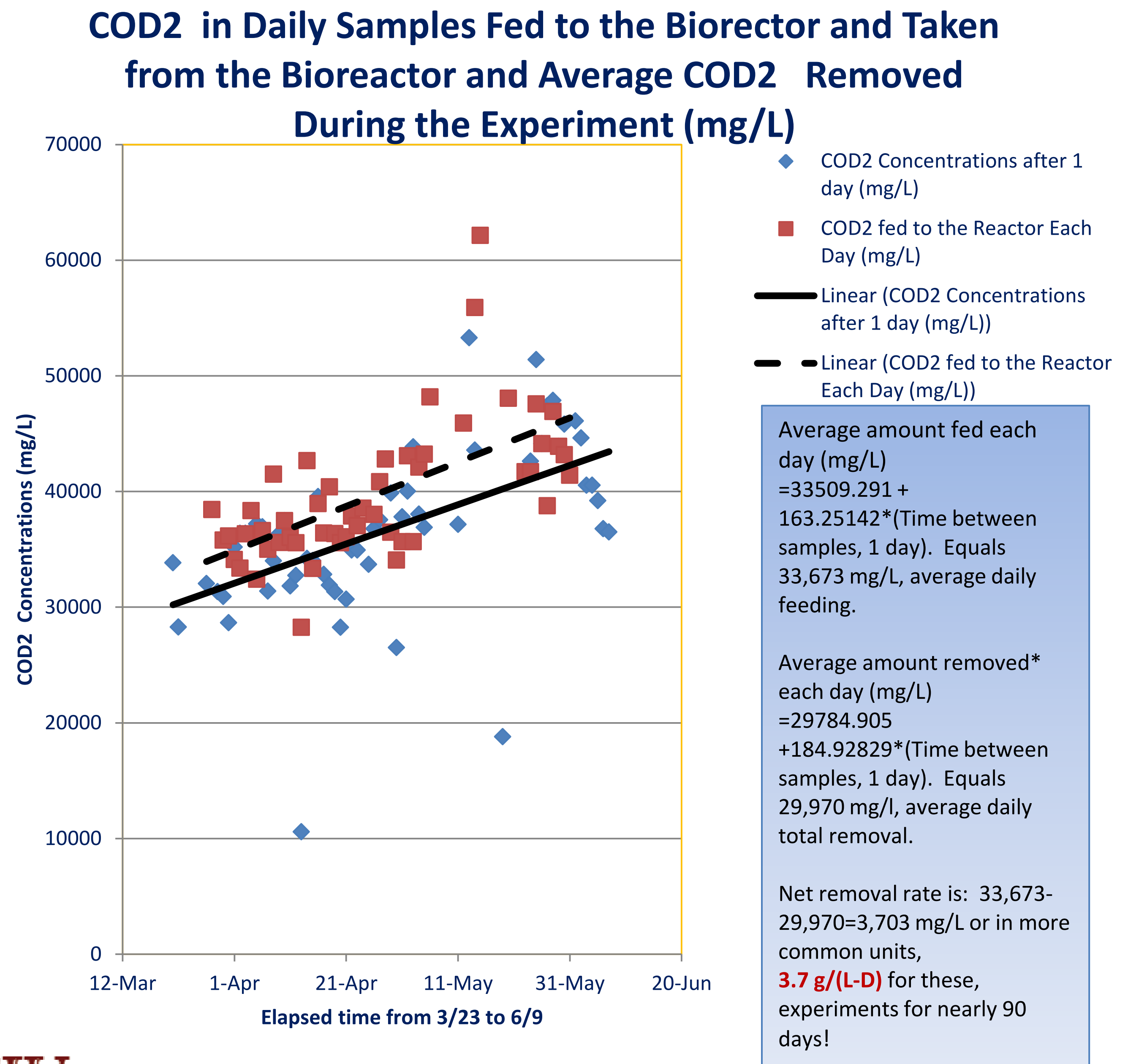


Figure 9. Heat introduced into the ATAD has a rapid and positive effect on ORP.

Figure 9 continues to support the hypothesis that heat can be produced in the weather windmill anoxic system. It measures the dominant electrochemical reactions in the reactor continuously. It is used to diagnose biological systems to establish whether they have ample oxygen to be aerobic most of the time (>0 mv), or possibly methane-generating anaerobic conditions (<-250 mv), or in the middle (anoxic). Our system quickly used the available oxygen but the ORP showed it was anoxic, except after the steam spike when it was aerobic for 2-3 weeks. Figure 9 demonstrates that a temperature increase in a highly insulated reactor occurs nearly all windspeeds in all of the experiments. This could lead to heat generation, other than that by solely aerobic reactions. (keep in mind that overall wind was diminishing the winter to spring of the run. Unfortunately reactor temperatures that also increased steadily over the runs (4 thermocouples in parallel) could only get us one-half the target reactor temperature from 29° to 34° degrees C, to 55°-65°. Over almost all the data, all the runs the reactor were mesophilic, potentially supporting higher levels of pathogens.



SIU Southern Illinois University CARBONDALE

Funded by a grant from the Bill & Melinda Gates Foundation through the Grand Challenges Exploration Initiative

Figure 10. Estimation of COD2 removed and calculation of average removal rate (also proportional to the aerobic biological heating rate). We had no way to estimate how much settled solids might have affected the results.

Figure 10 is probably the most important figure in this work. It was crafted by removing 10 gal/day of 100 gallons in the reactor liquid and taking samples for chemistry and micro-organisms. This produced a 10 day residence time. Then daily the 10 gal removed was discarded and 10 gal of feed were sampled, prepared and added. Compressed air was fed at high rates for 15 minutes or so to the reactor aeration to try to suspend suspended solids interfering with the analysis from day-to-day. When all data were collected, the feed from one day was compared with the reactor sample from the next day, and Figure 10 depicts the feed and effluent related for that 24 hour day. Suspend for just a minute the obvious data variability and group all the feed samples and compare them with the group effluent samples in blue, draw linear trend lines and note that the difference between lines is the amount of COD2 removal. The calculations are on the chart. A major finding is that the COD removal rate average is 3.7 g/(L-D) and this matches Swine Waste results in Figure 1.even though this feed is not at all like excreta.

A major focus of this work was to measure surrogate pathogenic bacteria conditions our system would develop and assess survival rates in real human feces. This would be very useful in developing the link between our work and what real infective pathogens do in excreta.

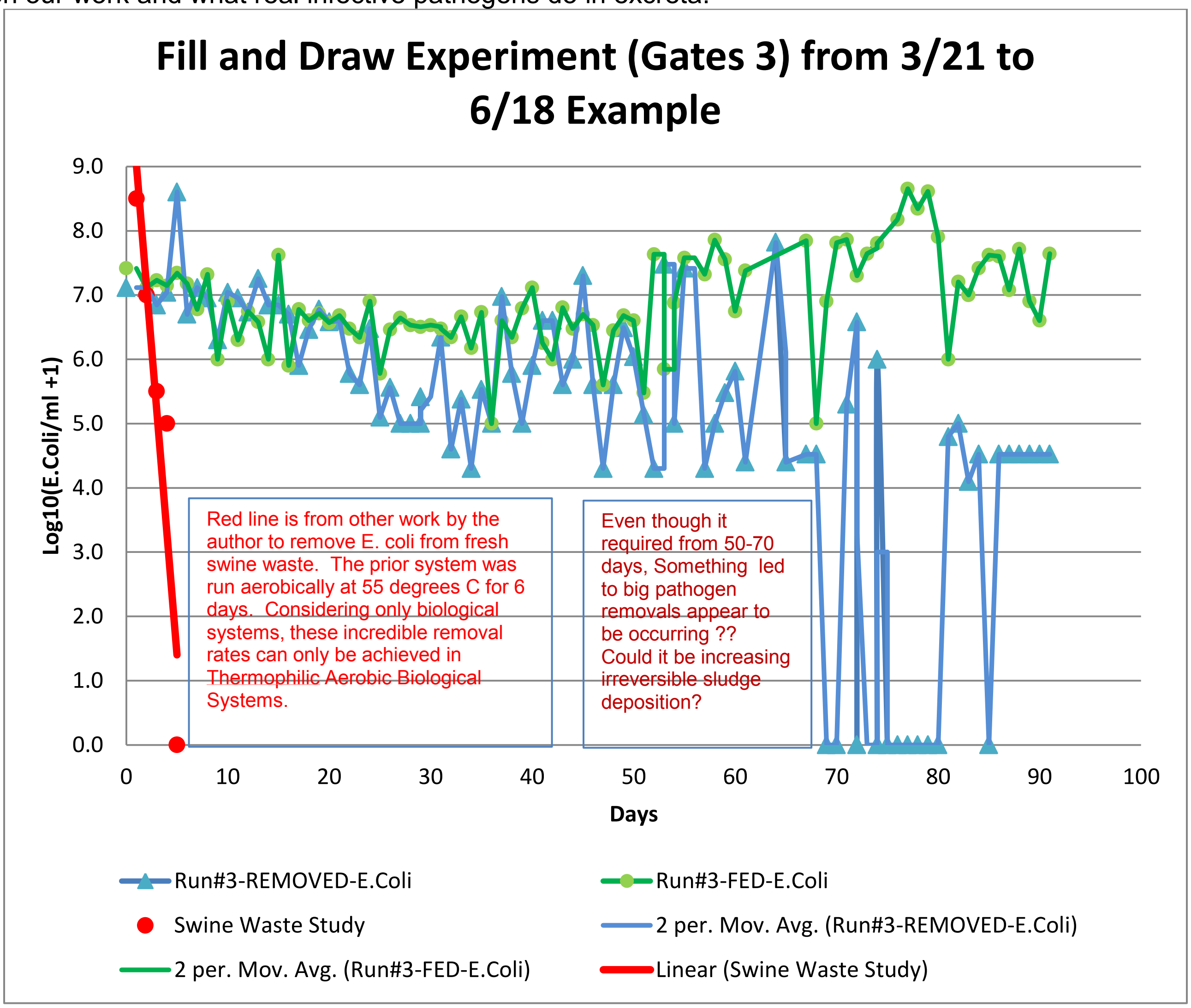


Figure 11. A typical result from our windmill-driven ATAD at 26-34 °C.

If you stipulate that because of reasons I have addressed, we were not able to reach the killing temperature zone in our 100 gal reactor, but only a maximum of 34°C, the ideal temperature for pathogen growth, then Figure 11 is just an example of the *E. coli* data typical for nearly all of the other runs and also the fecal coliforms.

This is a semi-continuous or “fill and draw” run. Some may also describe the operation as a sequencing batch reactor. To boost the COD2 of all Run 3, two gal of fresh cheese whey were added to the 8 gal of industrial waste feed each day With this we tried to see if we had a sensitivity to COD2 concentrations. For the first 20 days, there seems to be up to 10 organisms removal per day. From 20 to 60 days, the removal seems to be around 1000-fold and above 70 days, the removal seems to up to be an incredible 100,000,000 organisms per day. It is noted that we cannot determine how much of the solids which might sediment during the sampling. To try and minimize this we used a higher pressure air for around 15 min during the sampling.

For our swine work with E. coli, and swine waste we ran 1000 gallons at 55°C (after the reactor reached 55°C with an appropriate level of mechanical agitation). With a typical result from our past swine waste experiments for E. coli removal was above of 100 million-fold removal in 6 days. The ATAD reactor is the most effective biological system if the temperatures are held from 55-65°C for 10 days (EPA BIOSOLIDS RULES).

Conclusions

- Definite proof was attained that the Windmill-ATAD system is active at pathogen killing temperatures for at least several days in calm winds. Suggestions are that it may stay active destroying pathogens at times measured in weeks in appropriate further experiments.
- Strong rates of COD2 removal were confirmed supporting the generation of biological heat.
- Reactor Temperature increased during the runs over the 5-6 months even though the available wind dropped.
- Biological Heat Production was limited by one or both of these causes: 1) Possibly inhibitory feedstock, and/or, 2) an underpowered windmill system. Both are solvable and the 2012 SIUC Engineering Design Team has built and tested a windmill blower system nearly 4 times more effective than the manufacturer’s windmill.
- The 2013 Design Team is now working on the difficult future problems of mixing the system without electrical agitation.
- Since our water will be disinfected, a new device to attempt to make it potable water may be attainable.
- This area is worthy for continued development.

Sources of Support

- Appreciation for BMGF for the GCE 6 funding, this was essential.
- Department Chair, Provost and Chancellor.
- Windmill supplier giving important parts for free.
- Engineering Senior Design Class ME495 in the Fall demonstrated the invention for a highly efficient windmill and the current Senior Design Class of 2011 are developing strategies for reactor mixing of the reactor solids by wind only.
- A tremendous number of volunteers and Professors and other professionals, especially from the City of Carbondale NW WWTP and the City’s Analytical Lab.

COMMERCIALIZATION

1. A new high capacity windmill (up to 5 cfm) such as the senior design team has created must be built.
2. An appropriate system feedstock simulating human excreta must be made. Our current idea is to remove water from the primary feed in a cold process and take the 10 gal per day of solids as feed to our system. Composition and other factors will be closer to human excreta.
3. The processes of viscous mixing in excreta simulant will be studied in an ideal clear PVC reactor we designed.
4. The process of mixing with coarse bubbles at a high temperature, needs data for a large scale reactor without a mechanical or electrically mixing. These energy sources were banned in this study.
5. Simulated excreta viscous fecal mass will be studied.
6. The ability for the hot system 50-65°C to break down solid chunks of fecal material for complete pathogen removal, with and without mixing over the 10 days residence time will be investigated.
7. The processes of taking our water product and cheaply making it potable should be studied.
8. Any unwanted generation of methane will be measured.
9. From these studies an updated prototype should be built and demonstrated.
10. The system will be demonstrated in an underdeveloped country using wireless instrumentation so anyone authorized can watch the system data one their computer.

Acknowledgements

While many were involved in this work, I list a summary of the contributors below. Of course The Bill and Melinda Gates Foundation, are key to our efforts. Lucianna Mottala Lugo a key participant graduated, Dr. Rasit Koc, Chair of Mechanical Engineering and Energy Processes SIUC, Mike Imbayan , Current Graduate Student, Senior Design Team, Fall 2012, David Martin, BS employed, past leader of the Design Team , Chris Doty, MS Candidate, past leader of the design team, John Goodloe, Senior BS, Member of the 2011 Design Team, 2013 Design Team: Austin Montgomery (Team Leader), Cortni Townsend, Corey Arnold, Nolan Hancock, A.J Williams, Mohammed Ibrahim, Rasad Nageeb. Tim Attig, Mechanic, Brian Greer; Staff Electrical Expert, Mike DeVinney, MS, now working on PhD, City of Carbondale: Sean Henry, Adam Decker,(and his group), Brad Luebke (and his group), and Kimberly Cole and her group.