AC 2012-5212: USING A P3 FUNDED PROJECT AS PART OF A CAPSTONE DESIGN CLASS IN ENVIRONMENTAL ENGINEERING

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While many capstone design courses are limited to paper designs and some involve laboratory testing this design course was more comprehensive in scope providing for a realistic/professional learning environment. Over the past 15 years students enrolled in the capstone design project in the area of environmental engineering at Clarkson University participate in one of the national design competitions organized either by Waste Education Research Consortium (WERC) (http://www.ieenmsu.com/werc-2/) administered by the New Mexico State University or by the Environmental Protection Agency through its People, Prosperity and the Planet (P3) Student Design Competition for Sustainability (http://www.epa.gov/p3/).

Each year student teams are recruited from engineering, business and sciences during the early fall semester. Undergraduate students participate in the project by taking the course identified as an interdisciplinary course or as part of their capstone design course requirements. Graduate students could participate in this class to fulfill process engineering course requirements or as part of their Masters of Engineering project requirements. Teams are divided into subgroups to tackle projects in hand. Biweekly meetings during the fall allow for the subgroups to update the team on progress made and identify new tasks. The course instructor functions as the overall project manager making sure that identified tasks by the team were addressed and team deadlines were met. In addition, the course instructor serves as a knowledge board offering advice when requested by the team. The same class format was continued throughout the spring semester with the exception that the team met twice weekly during allocated class periods. Since fall participation is voluntary, additional students during the spring are incorporated into the existing team structure.

The focus of this paper is to describe the experience of the most recent three years, where students and faculty participated in a project funded through EPA's P3 program. While anaerobic digestion (AD) of farmwaste has been promoted by the USEPA for large farms, no solutions are available for small farm systems. The objective of this project is to determine the feasibility of using small-scale anaerobic digesters to increase the efficiency of waste-stream management and the utilization of renewable energy, and to improve the economic feasibility of small-scale farming of livestock. Five students (1 M.S. in Civil Engineering, 4 undergraduate) were involved initially in writing and submitting of the proposal in the Fall 2008. Upon receipt of the Phase 1 award the first team consisting of one graduate (civil engineering), four engineering and management, one chemical engineering and six civil and environmental engineering undergraduate students was assembled in the Fall 2009. Phase 1 (feasibility study) focused on laboratory investigations. In addition, eight local farms were surveyed to determine the types and quantities of substrates available as well as to collect samples of said feedstocks. Given the range of waste-stream on the farms surveyed a model farm size was developed on which the remainder of the Phase I was focused. While the farms surveyed were very diverse, dairy manure was predominant manure source. Surprisingly little additional waste feeds were identified at the surveyed farms. Additional waste included hay, waste feed, milk waste and some minor other organic compounds. Overall the available extra feed at the surveyed farms was approximately 10-15 % of the total waste feed.

Bench scale anaerobic digesters were operated for more than one month to investigate the effects of temperature, hydraulic residence time and feed composition on biogas generation rates and methane content. The estimated biogas production of the system was then used to calculate the value of the energy offset. A regression of historical monthly average prices for energy sources such as diesel, propane, natural gas was then used to project average monthly prices for the next 20 years. It was determined that the two most productive uses of the produced biogas were to generate electricity and to burn it as a substitute for propane. This offset was used in the calculation of the system's payback period. Due to the cost of power generation equipment the production of electricity is less cost effective than offsetting the use of propane as heating fuel.

Through the first phase project it was determined that the utilization of AD on small farms for the purpose of managing varying waste streams and decreasing fossil fuel consumption and cost was feasible at pay back periods of approximately 6 years. The feedstocks necessary to run the digester are readily available on farms where this system would be implemented. Although quantities of feedstocks may vary, through lab experiments it was demonstrated that in most cases any additional organic waste added to the reactor could increase the biogas production of pure manure. The student team successfully competed at the competition site in Washington, D.C. for Phase 2 (process validation) funding.

During the second phase (a two year timeline) of the project the students were tasked to build an AD prototype and assess its feasibility through its operation over the course of one year. Twenty four students participated last year in the initial part of the Phase 2 project. This team consisted of five first-year graduate students in environmental engineering, four engineering and management, two chemical engineering and thirteen civil and environmental engineering undergraduate students. The 2011/12 team consists of l4 students (2 graduate, 2 engineering & management and 10 civil & environmental engineering undergraduate students).

Some of the course accomplishments over the past year include

(1) the development and testing of a novel treatment process for farm waste energy generation,
(2) the organization of two farm community panels receiving feedback from stakeholders (i.e. farmers and extension service employees). During the panel students provided an overview of the proposed process and gave the audience the opportunity to critique the design. A DVD summarizing the open panels was distributed to the local extension services for further dissemination with the opportunity to secure further input in the design.
(3) the operation and implementation of a prototype system at a local extension farm and
(4) the communication of the process to government and industry stake holders through annual participation of the team at the P3 competition meeting.

In order to determine optimum process operating conditions, three laboratory scale reactors were operated throughout the first year of Phase 2 project. Three hydraulic residence times (HRT) were tested, 10 days, 15 days, and 20 days all using 5 liters of liquid volume mixed reactors operated at 37 ºC. As expected the 20 day HRT digester had the highest volatile solids (VS) reduction of about 54% followed by the 15 day HRT and 10 day HRT reactors which had VS reduction of 33% and 23% respectively. Since VS reduction is positively correlated with biogas production the longer HRT will yield more biogas, which was observed in the laboratory. Economic analysis determined that the cost of heating a 20 day over a 15 day HRT system is larger than the extra biogas yield. But the extra biogas production of the 15 day over the 10 day

HRT system was significant in terms of system economics. Therefore, a 15 day HRT system was chosen for the prototype system, which should produce daily approximately 0.9 liter of biogas per liter of reactor volume. Given that the prototype system has a liquid volume of 3,785 liters, approximately 3,400 liters of biogas are expected daily from the system. Over the past three months of operation the average biogas production rate was 3,000 liters/day, which is within 15% of the expected from laboratory experiments last year. Given that the biogas production rates were so close to the laboratory experiments, it is expected that the economic analysis based on laboratory data will also prove to be similar to the one for the pilot system, confirming that the process will have be economically viable for small farms located in northern U.S. with pay back periods of less than seven years.

Stakeholder input during the design process and product development is critical to maximize product acceptance. The students organized two public forums inviting a range of farmers from the area. The forums included a presentation of the proposed process, question and answer sessions allowing for the audience to provide direct input. In addition, audience participants were asked to complete a pre and post survey assessing their knowledge and interest in AD technology. Statistical analysis of the pre- and post-survey responses indicated that farmer's interest in AD technology increased due to the forum participation ($p=0.81$; $n=15$). It was also found that a medium negative correlation existed between a farmer's age and post forum interest, which implies that older farmers were less likely to become interested in AD technology.

The AD system has been assembled at the Cornell Cooperative Extension Farm in Canton, NY over the summer 2011 and has been operated daily by students. Automatic data collection has been implemented since this spring semester allowing for more in depth analysis of the system. A more detailed evaluation of the effectiveness of the leachate system and effluent composition is essential and is ongoing. The added value of the leachate process will be quantified this semester such that it can be specifically addressed in proposals to farmers. Similarly, the effluent composition will be evaluated with regards to nutrient composition, mass reduction, and utilization.

From an educational perspective students were involved in all phases of the design project including laboratory studies, the construction and operation of the prototype system, community outreach, data collection and analysis. Incorporating a three year research project within a class setting has been challenging in terms of balancing individual expectations and continuity; yet the overall learning experience for the students has been tremendous. Only two of the 53 students involved in the project participated in all aspects of the project (proposal through demonstration). Most of the other students participated in the course as part of their capstone design experience (one semester). Some funding was allocated for student labor to maintain the system over the summer months.

The biggest challenges of the project were to balance expectations of the funding agency and educational expectations as well as to maintain continuity between student cohorts. While funding agencies expect professional quality for all research phases there is tremendous educational value of students realizing after failure that their design can be improved. Thus allowing for iteration in the design and construction may be time consuming (and costly) but will yield improved student understanding and ultimately result in a better product. For example, the process design had to be significantly modified between years one and two after it was recognized that the manure present at small farms had significantly different material properties than the one used during year one. Dairy manure at small farms generally is hard-packed manure consisting of high solids content and bedding straw while manure of larger farms is scraped manure having lower solids content. Realizing that the manure from small farms could not be easily pumped required the modification of the initial process to dilute the incoming manure with digester effluent.

Student evaluations were generally positive (rated 3.9/5 (n=10) in year 1 and 4.1/5 (n= 23) in year 2 on the teaching evaluation question "how do you rate this course") but not all students appreciated this type of a learning opportunity. Students expecting to solve well-defined problems may be forced out of their comfort zone by exposing them to an ill-defined less-structured open-ended problem. This was particularly noticeable in year 1 of the project where initial discussions within the team made it clear that before a novel system could be developed students would have understand feedstock availability at small farms. As a result a survey instrument was developed and implemented providing the necessary data for laboratory studies and design. Given the 14 week timeframe, completing the survey delayed other design aspects to a later time point causing distress by some of the students. While the data collection caused distress to the students at the end of the semester, the availability of this data could be credited for a positive performance at the competition securing follow-up funding.

In summary, incorporating design competitions and longer-term research projects in design courses is an effective method of stimulating student interest while incorporating real-world design problems into the class room. The class format requires that the course instructor remains focused on project management ensuring the competition deliverables are met. For longer-term design projects, ideally underclassmen or graduate students are recruited in order to maintain continuity between student cohorts.

The preliminary data obtained from the pilot testing confirms that AD of farm waste at smaller farms can be energy efficient (i.e. more energy is generated than is needed to maintain reactor temperature) in northern climates. We anticipate that the economic assessment to be completed y the end of this semester will also confirm the economic viability of the process. Farmers who implement this system are expected to be able to pay off the system in a reasonable amount of time and generate profit thereby improving the outlook of their economic future.