Sustainable Water Filters in Southern Peru

Dr. Randy S. Lewis, Brigham Young University

Dr. Randy S. Lewis is professor of Chemical Engineering at Brigham Young University (BYU). He received his B.S. and Ph.D. in Chemical Engineering from BYU and Massachusetts Institute of Technology, respectively. He currently serves as chair of the Education and Accreditation Committee of the American Institute of Chemical Engineers (AIChE) and as an ABET commissioner for accrediting engineering programs. He previously served in several national positions of AIChE. His research interests include biomaterials development, engineering education, product design for developing areas, and the utilization of renewable resources for the production of chemicals.

Ms. Terri Christiansen Bateman , Brigham Young University

Terri Bateman is adjunct faculty in the Brigham Young University College of Engineering and Technology where she has worked with Women in Engineering and Technology at BYU, numerous mechanical engineering capstone senior design teams, the Global Engineering Outreach class, and the Compliant Mechanisms Research Group. She received her bachelor's and master's degrees in Mechanical Engineering from BYU and also worked at the Ford Motor Company as a manufacturing and design engineer in Automatic Transmission Operations.

Mrs. Michaela Sutton
Ethan Hasler
Miss Jessica Lee Williams
Jennifer J Irvin, Brigham Young University
Joseph Richley Hirt, Brigham Young University

Engagement in Practice: Sustainable Water Filters in Southern Peru

Introduction

Following the creation of Engineers Without Borders (EWB) in 2002, many universities and professionals have established EWB chapters to broaden their learning experience by participating in global projects of developing communities[1]. Similar to this effort, a two-semester multi-disciplinary course in the College of Engineering and Technology was established in 2007 at Brigham Young University to engage students from engineering and technology programs in the design and implementation of projects for developing communities in a global setting. The three-credit hour Global Engineering Outreach (GEO) course has involved over 200 students throughout the years with projects implemented in Tonga, Ghana, and Peru.

The focus of the GEO course is the design of small-scale projects in conjunction with community members that can be developed during an 8-month period preceding an implementation trip. The interdisciplinary course is limited to 20 students from engineering and technology programs who participate on one of four teams (five students per team). Teams are composed of students from two or more disciplines and are involved in concept generation, prototyping, and design reviews during project development. Extensive documentation from each team addresses milestones, communication with the community, social and technical constraints, concept and prototype development, testing and evaluation, and finances. This documentation is critical for transferring information from one year to the next. A typical GEO course involves 30-50% students who speak Spanish fluently, allowing students to directly engage with the communities throughout the development and implementation periods. Examples of past projects have included washing machines, bio-filter toilets, water purification, water storage, water pumps, water heating, and herbal tea packaging. The focus of this paper involves the design and implementation of water filters on the Uros Islands of Southern Peru. Previous publications related to the course have discussed training internationally responsible engineers[2], sustainability and impact[3], integration of sociology and engineering[4], GEO course insights[5], and social connectivity between students and communities[6].

The 70+ man-made floating Uros Islands, made from the local totora reed, are home to members of the Uros tribe. The community highly values their traditional lifestyle of hunting, fishing, and craft making. One challenging aspect of living on the islands is obtaining clean drinking water since Lake Titicaca is a key water source. Lake Titicaca, split between Peru and Bolivia, is one of South America's largest lakes and the world's highest navigable body of water. Unfortunately, areas along the shores are polluted as a result of untreated sewage, mining, and factory runoff[7]. Thus, drinking water directly from Lake Titicaca is unhealthy although the islanders continue to use the water. To help facilitate cleaner water, students from several GEO classes designed and implemented water filters over a period from 2010-2016.

Filter Designs

Beginning with the 2010-11 GEO course, students designed and implemented a low-cost water filter so that islanders using lake water could have access to cleaner water. The design involved a three-bucket system composed of 5-gallon buckets. The first bucket, filled with water, fed water into two successive buckets each filled with two inches of washed gravel at the bottom and six inches of washed sand above the gravel. The total cost was approximately USD 15. During operation, a few inches of water always remained above the sand to allow for the formation of a biolayer. A few of these systems were implemented on the Uros Islands and were used extensively during the first year. The main Peruvian contact cleaned the filter four times during the year following implementation by removing and cleaning all of the sand. Feedback following the first year showed that the filter took a long time to build and clean and that the support structure for the three buckets had some stability problems. Nevertheless, the filters were effective based on evidence that a child's frequent visit to the doctor for stomach problems was no longer necessary after the filter was implemented. Water analysis for this first design was not performed.

Based on feedback, student in the 2011-12 GEO course worked with several faculty members and a water laboratory manager from the local city to develop an improved water filter. The design involved a single 13-gallon trash can to remove the need for multiple buckets and to provide better stability on the islands. This time, 0.5 to 1-inch diameter gravel (1 ¼ inches high), 1-5 mm diameter course sand (1 ¼ inches high), and 0.15-0.3 mm diameter fine sand (13 inches high) were used. The effective filtration height was similar to the 2010-11 design. Sand was washed and separated using mesh and washing techniques. Three filters were built with several of the islanders. Water was poured, when needed, onto a diffuser plate to not disrupt the biolayer that formed on top of the sand. During operation, water always remained on top of the sand. Analysis showed that 99% of E.Coli and coliform were removed. The total cost was approximately USD 10. Feedback showed that adding water to the top of the bucket on a regular basis was tedious since the capacity was small (needed to fill every 30 minutes), manufacturing time was still more than four hours, maintenance was still time consuming, and that the islanders wanted an increased flow rate. Maintenance usually occurred after the flow rates diminished to an unacceptable level- likely due to sand fines working their way into the outlet pipe. By 2014, only two filters were still in use on the islands due to maintenance constraints since the filters were primarily maintained by one person on the islands.

The 2014-15 GEO students designed a process to provide a more defined sand size and layering method to improve flow rates and reduce cleaning (by minimizing fine sands from travel to the filter outlet). A taller one-bucket filter system was used and sand was separated into more sizes to reduce sand fines from entering the outlet pipe. The final design involved a 15-gallon bucket with 4-10 mm diameter coarse gravel at the bottom (two inches high) followed by 1.5-4 mm diameter fine gravel (two inches high), 0.5-1.5 mm diameter course sand (two inches high), and 0.15-0.6 mm diameter fine sand (12 inches high). Thus, the effective filtration height was approximately 15% higher than the 2011-12 design. Unlike before, sand was solely separated using mesh. However, the sand separation time of nearly six hours was much longer than the 2011-12 design. Although there was a longer construction time, a reduction in maintenance issues with near removal of fine sands was a justifying reason for the increased time. The major upgrade to this design was the addition of a 55-gallon water reservoir upstream of the water filter that also included a mesh pre-filter. A float valve was placed above the sand in the filter to control the flow of water from the reservoir to the water filter. Water was added to the reservoir via a PVC pump that was also developed by another GEO team. The addition of the reservoir drastically reduced the time to continually add water to the filter. The cost of this filter system increased to approximately USD 28, primarily due to the additional reservoir tank and the need to bring the float valve from the US. Testing of the water quality of the new system was inconclusive although the 2011-12 design was tested and showed complete ammonia removal and more than 90% removal of heavy metals. Five filters were implemented on the islands. Feedback showed that the filters functioned well although the construction time had increased drastically and one part of the system used a metal part that had begun to rust. The islanders wanted a system that had no rusting parts.

The most recent water filter design (2015-16), shown schematically in Figure 2, was designed to address some of the challenges of the previous designs. Similar to before, a 50-gallon water reservoir system with a mesh pre-filter was implemented upstream of the filter. The reservoir was filled with lake water using a PVC pump. Tubing (1/4" diameter) located two inches from the bottom of the reservoir connected the reservoir to the filter bucket. A float valve above the sand in the filter bucket allowed water to pass from the reservoir at a rate equivalent to the water flow through the sand filter. The height of water maintained above the sand during operation is based on the distance between the water filter outlet and the top of the sand layer.

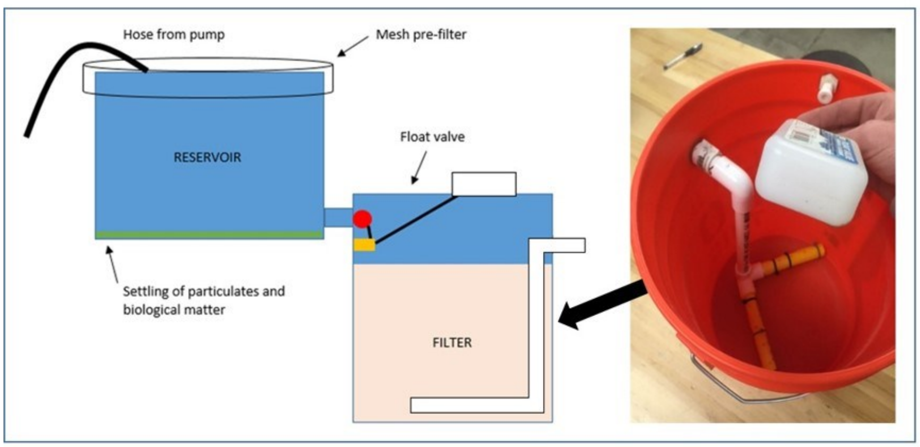

Figure 2. 2015-16 Water filter design

Due to the long sand separation time of the 2014-15 design, tests on water that was run through tubes of sand of different grain sizes led to the conclusion that multiple layers were unnecessary in maintaining the water quality. Rather, washed sand that removed the small sand fines was all that was needed. The fines still needed to be removed because they would potentially cause the outlet water to become cloudy and fines could also cause clogging in the filter. Washing sand was the most efficient method because it removed fines and it was quick and simple to perform. Basically, sand was sifted with a 2-mm mesh to remove gravel. The sand was then placed in a 5-gallon bucket and mixed with water (water to sand volume ratio was 3:1) for 10 seconds to suspend the fine particles. The water with suspended fines was removed and the process was repeated eight times until the water clarity showed little suspended fines. Enough sand was washed to create a 16-inch sand layer that could be placed above two inches of gravel within a 15-gallon bucket. The effective filtration height is similar to the 2014-15 design. The water outlet pipe was made of 1-inch PVC to prevent rusting and was placed in the gravel layer. The pipe was initially branched, as shown in Figure 2, and wrapped with 45-μm mesh to prevent potential clogging by sand working its way into the outlet. Approximately four inches of water remained above the sand layer during operation.

The current water filter takes less time to build (2.5 hours), has a fast flow rate (100-450 L/day depending upon time in service), and is easier to maintain. The cost of the filter was approximately USD 25. Water analysis during the design process showed that *E.Coli* could be reduced from 165 MPN/100 mL to <1 MPN/100 mL, turbidity could be reduced from 38.5 NTU to 1.77 NTU, and total suspended solids improved from 39.2 mg/L to 2.5 mg/L. Heavy metals were reduced to below detection limits and ammonia was completely removed. Eight new filters were constructed for the Uros Island, five of which were replacements for previously built filters.

Filter Constraints

During each design process, teams generated social and technical constraint tables to identify key measurable requirements to make the filters more sustainable. Social constraints represent the social and cultural needs or considerations of the design, such as the portable weight of the filter. Technical constraints represent the practical needs or limitations such as flow rate requirements. Identifying the constraints, and continually updating them throughout the design process, helped students define product specifications and provide context to communication needs. For the filter system, the primary technical constraints were the quality of water and flow rate of water while the primary social constraints were minimizing the time and difficulty in building and maintaining the filter.

The flow rate constraint for one filter was estimated as 300 L/day based on cooking and drinking water needs by the primary contact on the islands. The water quality was monitored throughout the design process based on health standards for drinking water identified by the World Health Organization. The most critical health standard is an E. Coli population of less than 1 MPN/100 mL. Next, in order of importance is turbidity (< 5 NTU) and total suspended solids of less than 20 mg/L. Other requirements pertaining to ammonia, phosphate, and organic levels are not as critical, but still very important. The most significant social constraints are the time and difficulty to build and maintain the filter. The key contact indicated that a construction time of one to three hours for one person would be ideal. The islanders were less willing to maintain a filter if the filter was too complex to build and maintain.

Community Engagement

Throughout the two-semester course each year, students stayed in frequent contact with primary contacts on the Uros Islands and in the nearby city of Puno. Students on each team who spoke fluent Spanish usually made contact by phone (incoming calls do not cost the islanders) or email on a biweekly basis. The key contact on the Uros Islands was an entrepreneur who owned, operated and maintained a water filter since the students first implemented filters on the islands. In addition to his own filter, he also helped maintain other filters on the islands. The contact understood the challenges that occurred in each successive design and made suggestions on how the design could be improved to better suit the people on the islands. His enthusiasm for certain aspects of the filter, especially the reservoir, assisted the teams in discerning what should be retained from previous iterations. Additionally, the contact provided information on what life is like on Lake Titicaca- first-hand experience that is hard to find elsewhere. The most difficult part of communicating with the contact was poor reception which led to ineffective understanding on some occasions. Nevertheless, the communication has been effective enough to provide feedback on the designs each year and to facilitate a relationship between students and the contact that have bridged across successive classes.

As part of documenting community engagement, students were required to develop an interview guide that involved a continual update of questions and answers associated with categories (e.g. community structure, work environment, etc.). These questions provided a guiding document to keep the student teams focused on critical questions that aided in the design during the development process. Instruction on developing the interview guide was provided each year by a sociology professor. In addition to the guide, students meticulously documented all contact interaction. An example of the contact interaction is shown in Table 1 with the name of the contact removed for privacy reasons. An advantage of the documented interaction is that students could observe the effectiveness of their contact methods and provide information for subsequent teams. At the end of the project development, the team stated that nearly 50% of the phone calls were answered and that over 40% of the contribution to the filter design came from the Peruvian contacts.

Table 1. Contact documentation table.

Contact Date	**Name contacted**	**Method**	**Contact Details**
9/17/15	Primary contact	Phone	Discussed the current filter in use and the rust developing. Learned more about his life and family. Established a consistent time to call every week.
9/23/15	Primary contact	Email	Sent a brief bio of each team member and expressed our enthusiasm to work with the contact on this project.
9/24/15	Primary contact	Phone	Called with the pump team and discussed the different individuals on the islands with pumps and filters. Asked for a list of the individuals and their contact information to be sent to us.

Implementation

Each spring, student teams implemented the filters in Peru as part of a 16-day study abroad trip. Because relationships were built via bi-weekly phone calls and email contact during the 8-month GEO course, several islanders were familiar with the students and were valuable resources of information. During each trip, these contacts worked side-by-side with the student teams throughout the building process and attempted to learn for themselves how to build the filters.

The majority of the parts for the filters were purchased in Puno, a city on Lake Titicaca, close to the Uros Islands. The focus of building with Peruvian parts was to make sure that the filters could be maintained with items that were available locally. A few parts (float valve & brass nut) were brought on the trip from the US to ensure that the filters could be built quickly because students and professors had been unable to find those parts in Puno (though they may be available in Lima or other places in Peru). Documentation was also provided to each family who received a filter to teach them how to maintain the filters by cleaning the sand and replacing parts if needed. Filtration testing was completed before the trip to ensure that the filters would be adequate to serve the needs of the people in Peru.

Obtaining contact information for members of the Uros community who had broken filters from previous implementation trips and then speaking with them has been a great source of information in attempting to discover why the filters stopped functioning. Remaining in contact with the stakeholders of the filter project has been essential to its success, especially since both the islanders and students have recognized the long term commitment between both groups. Overall, the Peruvian contacts continue to be an invaluable resource in the planning, analysis, design and implementation process.

Future Work and Conclusions

Water filters have been a valuable resource for the islanders as evidenced by their feedback on better health and cleaner tasting water. Continual design iterations over successive years with near bi-weekly communication with the Peruvian contacts has provided a sustainable model for student teams. The development of relationships over the years has provided continuity between students in successive GEO courses. Future opportunities include additional water testing of nitrates and phosphates as well as the continued monitoring of pH, turbidity, dissolved solids, total coliform, and *E.Coli*. Long term testing of water flow rates with water quality can also provide a more detailed understanding on the lifetime of the filter.

Additional improvements on the water filter have the potential to make the system even more reliable and sustainable. Currently, the float valve and the brass nut utilized for the filter are purchased in the US. Future efforts should be performed to find Peruvian resources for these items. Furthermore, the Peruvian contact expressed concern with the metal components of the float valve which do rust overtime. Complete elimination of any metal in the system is an important constraint.

Acknowledgements

Special thanks is given to WesTech, specifically Mark Fisher and Bryce Myers, for volunteering their expertise, time, and facility resources for testing of the water filter and suggestions for developments. Dr. Aanderud and his staff at BYU also provided testing equipment and facilities for the water analysis. Finally, Michael Sweany, the TA for the GEO course, provided consistent support, suggestions and efforts for the latest filter design.

References

1. http://www.ewb-usa.org/myewb/find-a-chapter/, Accessed 1/19/2017.
2. Frankman, A., Jones, J., Wilding, W.V., and Lewis, R.S. "Training internationally responsible engineers", *Proceedings of the 2007 ASEE Annual Meeting*, Honolulu, HI 2007.
3. Geddes, J., Wilding, W.V., and Lewis, R.S. "Sustainability and impact of global projects", *Proceedings of the 2009 ASEE Annual Meeting*, Austin, TX 2009.

4. Garff, P., Dahlin, E., Ward, C., and Lewis, R.S. "Analysis of integrated engineering and social science approaches for projects in developing communities", *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, Special Issue: 137-150, 2013.
5. Lewis, R.S. "Insights from a global engineering outreach course", *International Journal for Service Learning in Engineering, Humanitarian Engineering and Social Entrepreneurship*, Special Issue: 256-268, 2014.
6. Lewis, R.S., Bateman, T.C., and Ward, C.J., "Social connectivity assessment of global humanitarian-based projects", *Proceedings of the 6th IEEE Global Humanitarian Technology Conference*, Seattle, WA, 2016.
7. Valdez, C. "Frog die-off in Lake Titicaca puts spotlight on unchecked pollution that threatens livelihoods", U.S. News, June 25, 2015. (http://www.usnews.com/news/world/articles/2015/06/25/unchecked-pollution-befouling-majestic-lake-titicaca)