PASSIVE SOLAR DISTILLATION OF ARD WATERS

CONTRIBUTIONS OF AGUSTIN CACERES

Task number two for the 2017 International WERC Design Competition challenged participants to design and build a system capable of treating 10 mL per minute of acid rock drainage (ARD) without requiring power supply or frequent maintenance. The task developers proposed two possible methods: passive sulfate bioreactors and passive solar distillation. My first assignment was to research additional alternatives to treat the ARD. I discovered that permeable reactive barriers, ion-exchange columns, and limestone catalytic beds are some of the currently applied technologies to remediate the water. The problem with the first two methods was their high levels of affinity. Therefore, either the active component of the barriers and the medium in the columns would have needed to be replaced after a batch of ARD was treated or several of these units would have needed to be placed in series to remove all the contaminants present in the water. Also, none of these two alternatives was economically feasible. The third method was less expensive, but it had low efficiency, and produced inconsistent results. After consideration of these issues, none of these alternative was implemented by the team, so my research then focused on one of the solutions proposed in the task description.

After the rejection of additional alternatives, I was assigned to research bioreactors instead. This method utilizes anaerobic bacteria that feed on sulfates and reduce them to sulfides, which then precipitate upon reacting with most metallic ions in ARD. Unfortunately, some of the sulfide ions react with hydrogen instead of metals, releasing the poisonous hydrogen sulfide gas, which was the greatest reason to discard this alternative. This method was also discarded because there was not enough information available on how to cultivate and grow the bacteria and prepare an adequate substrate medium for their reproduction. The complexity of creating and maintaining anaerobic conditions also contributed to that decision.

Having only one solution remaining, passive solar distillation was the next topic to conduct research on. Optimum elevation angle, shape of the roof, materials of construction, improvement techniques, and environmental conditions for Bisbee, AZ and Fayetteville, AR composed the core of my research work. After all of these were identified and selected, condensation site (if any) and sizing of the still were the following areas to approach. Information on ARD properties such as pH, conductivity, and temperature of precipitation was needed to ensure the resistance and durability of the selected materials. In order to determine these properties, I purchased the necessary chemicals to prepare a fake ARD sample. Once all the initial design considerations had been revised and approved, I ordered the materials to start constructing the bench-scale prototype. The original designed suffered several modifications, so more materials, tools, and equipment had to be purchased as well. During operation of the still, condensation formed on the polycarbonate roof. This was an undesirable event because having water on the inner surface of the roof reduces its overall heat transfer coefficient, making the prototype less efficient than expected. Consequently, research was done on how to eliminate inside condensation, which resulted in applying a hydrophobic coating to the roof. Since this was a temporary solution, fans were installed to exhaust the steam thus preventing condensation once and for all.

2017 WERC Contest Involvement

Caitlyn Chambers

The University of Arkansas-Task 2 WERC team developed a completely passive solar distillation design with the capability of treating acid mine drainage. Over the course of the Spring 2017 semester, I completed several tasks related to this project: literature research, data mining, experiment monitoring, development of visual aids, economic analysis and presentation of results.

Solar distillation is a well-researched field, and as such, extensive literature reviews were conducted to select an appropriate small-scale design that could feasibly be scaled up. Literature review summaries I provided to the group included detailing the chemistry behind ARD formation, case studies on commercial uses of the sludge, sludge removal feasibility through utilization of a vacuum truck, building code considerations, polycarbonate instillation guidelines, the review of a polycarbonate technical manual, and determination of orientation providing greatest solar capture over a full year.

Information gathered from several governmental databases were utilized to inform our design. Specifically, I compiled information regarding soil characteristics in the area, number and types of mine site locations, weather patterns, and solar radiation averages.

Each team member took shifts setting up experimental runs, recording data throughout the course of the experiments, and providing documentation in the form of written observations and pictures.

I authored the introduction and economic analysis portions of the paper. For the economic analysis, I produced a capital cost breakdown for the cost of a single full-scale solar still. Through research, discussions with our mentors (Drs. Penney and Ackerson), and interfacing with vendors, I produced a total project cost estimation, including labor. I also helped extensively with editing of the final paper and poster.

I attended a visit to the Fayetteville Biosolids Plant, which aided in confirming humidity as a key variable in our design, which could be successfully mitigated by expelling air from the system.

I developed the first iteration of visuals and slides that the group used to present our design at competition. During the competition oral presentation, I presented the economic analysis I had developed, as well as regulatory and safety considerations taken into account by our full-scale design. I also represented the department by presenting our team's poster at the 2017 STEM Poster Competition on April 27, 2017.

Luke Galuska

WERC Honors Report

At the start of the WERC competition, I established contact with Jerry Roose, the North American Environmental Operations Director of Freeport-McMoRan and Brett Waterman, who wrote the problem for task 2. I was able to organize a trip for three of my team members to visit one of their legacy mining facilities. This proved to be invaluable as it gave us a more accurate understanding of the problem which our competitors did not have. This trip also allowed us to tailor our project to the Copper Queen Mine.

During the initial research phase I helped organize our team to research solar stills, reverse osmosis, sulfate bioreactors, and other possible technologies. I researched the various solar still designs including a single-slope basin, pyramid, double basin, hemispherical, compound parabolic concentrator- tubular, and others. We decided to use a single-slope basin solar still because it is the easiest to construct while remaining completely passive. In addition, I researched multiple ways that we could improve the efficiency of our solar still. These include: using vertical wicks, reflective inner walls, hydrophilic coatings, exhaust fans, dying the water black, and heat integration. The still was designed to be tested using a reflective back wall, but do to unforeseen issues we were never able to proceed to that portion of the experimentation. We implemented the use of hydrophilic coatings during the initial experimentation process, to decrease the fogging effect on the transparent top and to increase the solar flux into our still. This was effective but only lasted a short time. After talking with five vendors about buying a permanent hydrophilic coating it was determined that the coatings would be too expensive and inefficient for our needs. We settled on the use of exhaust fans to decrease the quantity of condensation on our window as well as to expel the water vapor.

I did significant research on what materials would be best for the design of our transparent cover and the basin liner. Various types of glass and polymers were researched for the transparent window. The top three materials were low iron tempered glass, Plexiglas, and polycarbonate. Low iron tempered glass had the best characteristics, but it was considerably more expensive than the other options so it was not economically feasible. Plexiglas is lower cost and has high transmittance, but it has a service temperature of 70 degrees Celsius which was shown to be below the operating temperature of the solar still. Polycarbonate was chosen as the transparent material for the solar still due to its low cost, high transmittance of visible and near IR solar radiation, high impact resistance, high service temperature, and its opaqueness to long IR radiation. Ensuring that the polycarbonate was opaque to long IR radiation was a difficult task as not much research has been done in that area. However, it was determined that the polycarbonate was indeed opaque to long IR radiation through literature research as well as calculating the range of radiation wavelengths that the solar still would emit. I also researched materials for our basin liner when our LDPE liner proved to be ineffective. The best liner for our needs was ethylene propylene diene monomer (EPDM). EPDM is a synthetic rubber liner that is flexible, puncture resistant and has great UV stability. This liner also has a good service temperature range of -50 Celsius to 150 Celsius, while being acid resistant up to 3M sulfuric acid at 71 degrees Celsius. However, we were not able to obtain this liner and chose to use polyvinyl chloride (PVC) to mitigate the leaks in the basin. This liner was not the optimum choice as it has a low service temperature and with continuous use can become brittle. Despite this, it was chosen for its excellent water retention capabilities which proved very effective at stopping the leak in the basin. In addition, it was determined that for short use there would be no adverse effects on the solar still except for a small release of plasticizers at maximum operating temperatures.

I was responsible for transporting the building materials to process dynamics where we built the apparatus. I helped with nearly every step of the building process. This includes: building the frame, attaching the basin liner, polycarbonate, and the Styrofoam insulation. In addition, I helped set up and take down the solar still numerous times as well as measuring the daily output.

I wrote the executive summary for our report as well as the bench scale and scalability sections. I also helped edit the report on several occasions. In addition, I created the pamphlet that we handed out at the competition as well as creating a list of questions and answers to prepare our team for questions that the judges might ask. I also helped the presenters practice presenting on an individual and group basis. The goal of this was to ensure that they felt confident in their presentation abilities.

During the competition, I was one of the primary team members in contact with the safety team. This proved to be beneficial for multiple reasons. First, it ensured that we met the standards of the competition for safe operation of the solar still. Secondly, we were able to determine the purity of our distillate sample by obtaining the total dissolved solids analysis. This allowed our team to inform the judges about the water purity that the solar still could achieve. This was particularly important as the still had not yet been operated with the contaminated water during the experimentation process and therefore we had no purity results to report. Thirdly, another team member and I made sure to document the measurement process for determining our system's flow rate. This proved to be vital as the judges requested proof that we achieved the flow rate that we claimed to have. Lastly, I was one of the primary team members to answer questions about the bench-scale apparatus as well as participating in the peer review process.

As a member of the 2017 Task 2 (Passive Solar Distillation of ARD Waters) WERC team, I made several contributions to our project that aided in the success of our endeavors. These contributions included conducting preliminary research on a specific technology used to treat acid rock drainage, assisting in building and implementing the necessary design changes to our apparatus, constructing a mathematical model that would approximate the still's performance under a specific set of operating conditions, and presenting our team's project at the competition. These tangible efforts were a portion of the overall hard work that was required for the team's success.

Before building our bench scale apparatus, each team member was responsible for researching the effectiveness of a specific technology used to treat acidic water. I, specifically, researched the use of passive sulfate-reducing bioreactors in the treatment of acid rock drainage (ARD). Passive sulfate-reducing bioreactors take advantage of a biochemical reaction in which desulfovibrio (sulfate-reducing) bacteria reduce sulfates into to sulfides. The sulfides from this reaction precipitate metal ions in the acid water and effectively purify ARD. Ultimately, our team decided not to use this technology going forward due to its potential to produce hazardous hydrogen sulfide gas and known futile efforts by legacy mine sites to contain the gas.

Several design changes and alterations to our bench-scale apparatus had to be implemented for it to yield the desired results. After observing an abundance of condensate on the still's polycarbonate sheet during our first experimental trials, I theorized that a high relative humidity in the still's vapor space was not only contributing to the "fogging" of our polycarbonate sheet but also reducing the potential for a higher evaporation rate. With this thought in mind, I recommended that the team drill multiple delocalized outlet holes in the back of the still, thus allowing for a larger volume of saturated air to flow out of the still (aided by the use of small exhaust fans). I collaborated with my teammates in drilling the necessary inlet and outlet holes for fresh air entering and saturated air exiting the still, respectively. I also attached the insulated piping to our outlet holes.

By developing a set of differential equations based on heat and material balances performed on the apparatus, I was able to construct a transient model (using MATLAB software) that would predict the still's performance (pilot-scale and full scale) with the assistance of one other team member. The results shown in the following figures depict the expected amount of water to be evaporated under a specific set of environmental conditions in Las Cruces New Mexico.

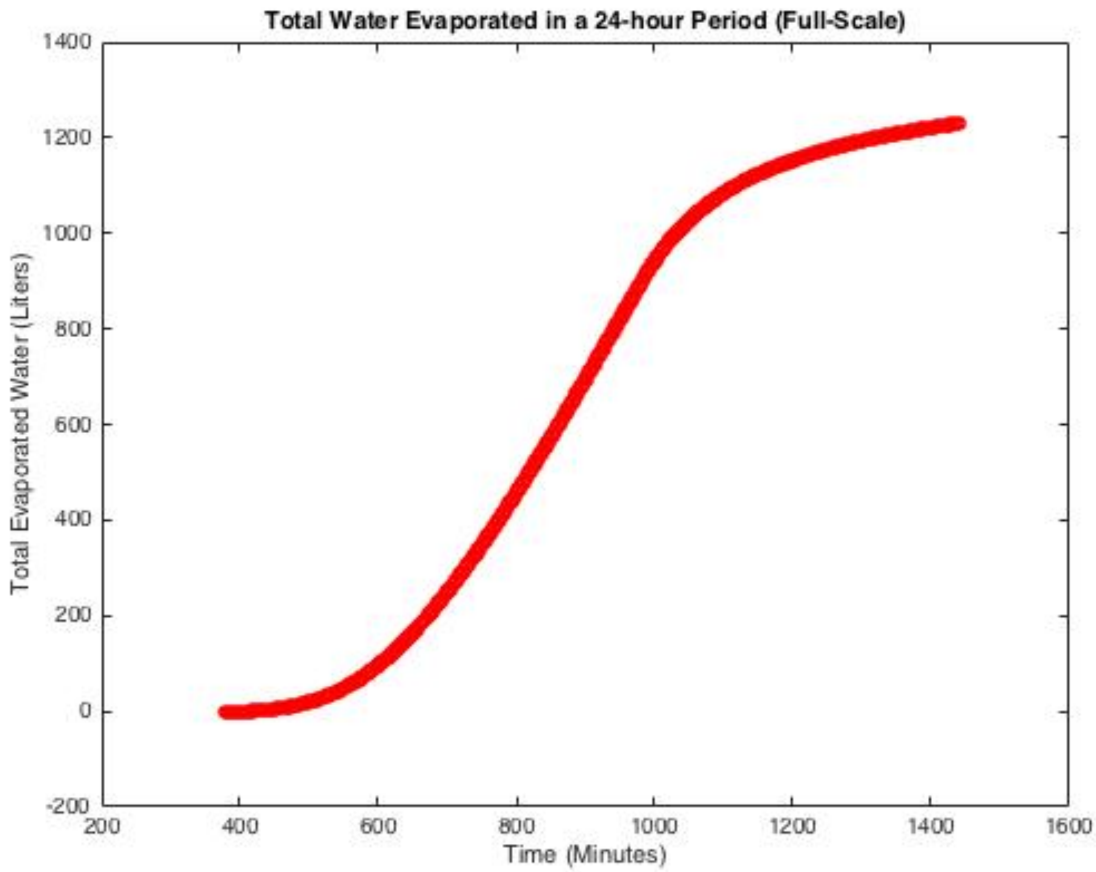

Figure 1: Total Water Evaporated in a 24-hour Period (full-scale design)

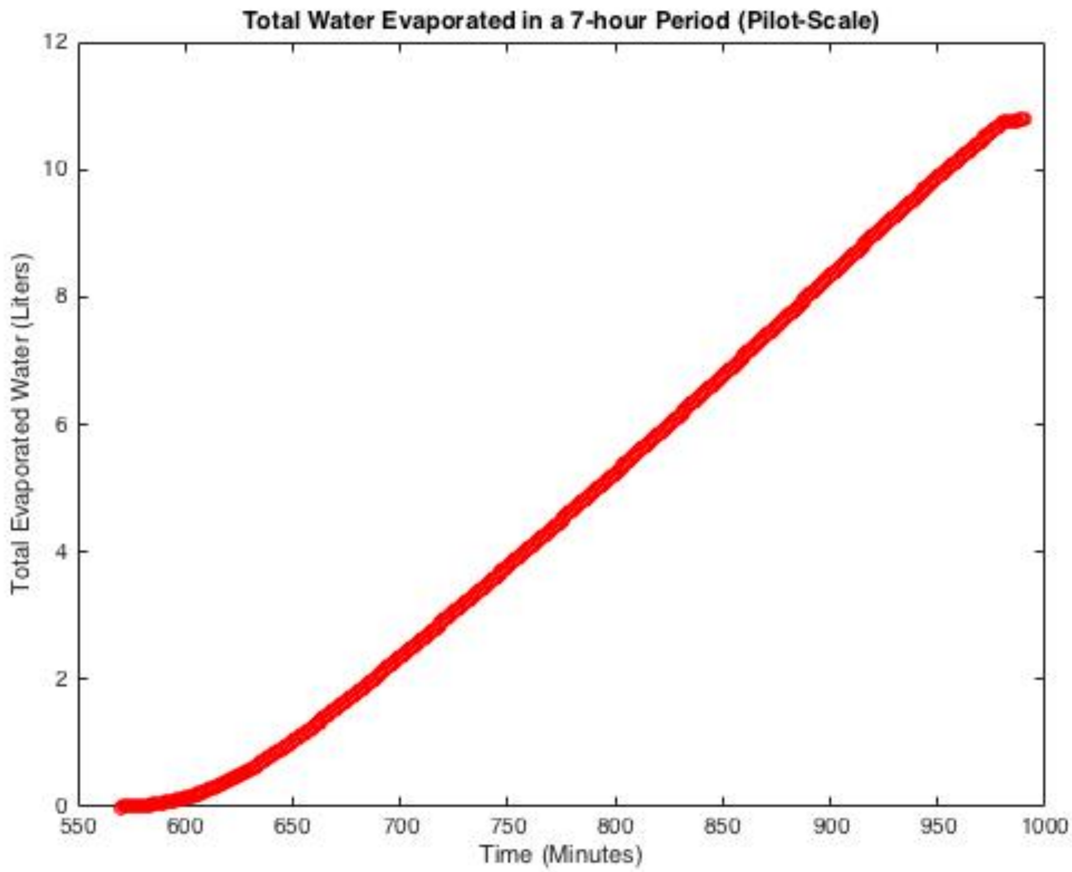

Figure 2: Total Water Evaporated in a 7-hour Period (pilot-scale design)

Correlations from literature were used to quantify specific heat and mass transfer coefficients, as well as material properties, that were necessary for the model to perform its calculations. The pilot scale mathematical model predicted the evaporation rate within a 10% error at the competition.

As a presenter at the competition, I explained to the judges the functionality of our apparatus, the transport phenomena that occurred within the boundaries of the system and the still's anticipated performance once implemented at one of legacy mine sites.

Author: **Chris Graham**

Alex Raney
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Honor’s Thesis

WERC Project Reflection

This research project was to design a system that could treat acid mine drainage. The system had to require minimal maintenance, operate in remote locations, and be effective. I would like to clearly state that completion of our WERC task was very much a team project. My team worked well together and were able to accomplish a great thing.

During the initial research phase, I investigated the design of solar stills. This involved familiarizing myself with the terminology, common design characteristics, methods for improvement, and the materials used. This knowledge greatly benefitted the team when we were discussing and finalizing our plans. We were able to discredit some designs we thought of and improve on our final solution using what I had learned.

I also had several other research duties as the project developed. A main problem for this project was designing a way to condense the water vapor outlet. I designed a PVC heat exchanger system that used ambient ground temperature to cool the vapor. This required modeling the system and finding the average ambient ground conditions. I then priced the system. We decided to not use this system because it was prohibitively expensive.

The final conceptual aspect I worked on was the full-scale design and operation. Another team member and I thought through the materials of construction and design. We also designed the operating procedures that would need to be implemented with this process. This involved also considering the safety and environmental concerns associated with the project.

My contributions were not only in the conceptual aspects of the project. Two other members and I went to visit an actual inactive mine site in Arizona. I recorded all our notes from this meeting and informed our team members what we had learned. This visit, and the knowledge gained, was instrumental in designing our still.

I took the initial lead on physically building our still. Most of the team members had not used power tools for major construction. After the wood was cut, we were able to build our still quickly to begin testing. I also led construction and modification of the still. We had to redesign our polycarbonate roof attachment to make it more robust and prevent leaks. This involved precision drilling through aluminum and polycarbonate without damaging the polycarbonate. The last major design change we had to do was install fans along the back and inlet air holes in the front.

I oversaw installing and operating the fans. We used standard computer fans that had to be rigged up to connect to our batteries and power supply. My experience wiring fireworks helped immensely to making our electrical system work and be safe. I had to wire each individual fan and then connect the two to a single power source. Our power source was very antiquated and difficult to deal with. The supply was also confusing which caused us to fry our first two fans. The fans were pivotal in operating our still efficiently and meeting the project goals.

This paper outlined my specific contributions to the team. Having initial knowledge of solar stills helped with our design. Visiting the mine in Arizona gained our team an immense amount of knowledge. Finally, my carpentry and electrical knowledge helped to bring our design to life and operate wonderfully.

Stephanie Shreve
Honors Thesis Reflection
4/27/17

The design project I completed for my senior design thesis involved competing on a team of eight members to compete in the WERC international environmental design competition. We entered a design in the Passive Solar Distillation of ARD Waters category and won first place as well as the Freeport-McMoRan Copper & Gold Innovation and Sustainability Award. This paper serves to state what my contribution to our project entailed.

Last semester when our team was put together for the purpose of completing our design project, coordinators were selected to help the team work more efficiently. I was selected to have the responsibility of being the team coordinator. This required me to be the organizer of our team and ensure that our design work ran smoothly. The first month of working on our design consisted of a mass amount of research to be done by each member of the team. Every design consideration for solving the task at hand was thoroughly researched by at least one team member before a decision was made to approve or discard the idea. In addition to doing my own detailed research, which consisted mostly of passive bioreactor and pH neutralization technologies to treat mine waste water, I delegated each research task that needed to be accomplished. When a decision was made on a design consideration, I ensured that a fair decision making method was used, and that every member of the team had a voice in the decision. I implemented positive and negative lists that were completed objectively before opening debate among team members, and then often had to step in to regulate the direction of the conversation to stay on topic and ensure that team members who did not speak out were heard just as equally as others. Having a team of eight members made all decision making a large effort since there were often many differing opinions. Organizing the discussion and decision making processes for the team taught me a great deal about communication within a group of many different personalities.

Once the team moved out of the research-heavy phase of our design project, we chose to design a passive solar evaporator to treat acid mine waters. From there on out we had meetings twice a week with our two advisors to discuss our progress and ideas for improving our design. I led these two hour meetings by creating agendas for what needed to be discussed as well as keeping a binder with relevant research items and calculations done by the group to be used as references in our discussion. I kept track on paper of what was said, as many small but important things were discussed during each meeting. As team leader, the burden fell on me to be most prepared for these meetings. This taught me in a very real-world-like application, what it will be like to report to supervisors in the industry and lead discussions about design work.

There were countless daily organizational and delegation tasks I accomplished as team coordinator, however there was also work I contributed to the actual design of our solar evaporator that is worth mentioning. Before we were cleared to start building our prototype, our advisors required a thorough consideration of all design dimensions and materials of construction as well as calculations predicting the performance of the solar still. I calculated solar capture area needed for our still based on the design competition's required flow rate of clean water produced, and made decisions about the lining and polycarbonate roofing materials of the solar still. As the team moved on after building our initial prototype we looked for ways to improve its performance by testing many design iterations for how to increase the amount of pure water that was evaporated from the acid mining water mixture. I took on the task of completing the calculations to determine the dry air flow needed in order to keep the relative humidity inside the still low enough to promote evaporation, and the flow rate produced by the fans in our design that were there to draw out the evaporated water from the system. These calculations were time intensive and required multiple edits. This was a key parameter of our design and the calculations I produced were used to design our theoretical full scale design based on our prototype that had chimneys which naturally expelled the evaporated water to the atmosphere. The calculations were used to determine the dimensions of the chimneys for the amount of water that was being evaporated. This part of our design was vital to the team's success as it made our proposal completely passive, not requiring any electrical power, and minimal maintenance, which was a major request of the mining company who sponsored the project.

Before going to the competition, I contributed a significant amount of work to our final paper that was submitted two weeks prior to presenting our design in New Mexico. I completed the bench-scale and full-scale design portions of our report as well as the mathematical modeling description. Once other team members completed their contributions, I thoroughly edited the report multiple times before sending it to the competition's coordinator. In addition to our paper, a poster was made before arriving at the competition that would aid in our demonstration of our prototype unit for the judges. I completed the final design of this poster and printed it for the team. At the competition four of the team members gave the formal oral presentation of our project to the judges and I was one of the four to do so. This design competition was a great learning experience for me, and I was able to improve on my communication and presentation skills in a very professional setting. The competition involved intense question answering for multiple panels of judges during the demonstration of our bench-scale solar still that we brought to New Mexico, and I was present during the entirety of the day to answer these questions.

Anna Stoller
April 27, 2017

WERC Competition Contribution

During the course of this competition I played an integral role in this project. My responsibilities included: research of the regulations of our topic, the construction of our physical model, the theoretical conception of our ultimate design, as well as the creation of the safety requirements of our design, and finally the presentation itself. This project was an incredible learning experience, and an invaluable experience. The skills I have developed throughout this project will forever be of great importance in my future endeavors.

My preliminary research started late last semester and over winter break included governmental regulations and limitations on acid rock drainage including containing and discharging it. This includes the pH and concentration allowed for discharge of the pollutants in the acid rock drainage both nationally and regionally. During the first week as a group, I helped research and rule out the idea of using a bioreactor as our solution. I also did research on different iterations of our chosen solution, the solar still. This included the use of wicks and the advantages and disadvantages of double- and single-sloped tops. Weather conditions including wind speed and gusts were another part of my research. Lastly, one of my other big research topics was on landfills and what we could and could not put in a landfill from our leftover sludge produced.

Another big area of contribution was on the construction of the bench-scale unit. A main part of construction I dealt with was the low density polyethylene (LDPE), or basin liner. We were having trouble with it leaking. I helped to research adhesives to try to fix holes when we thought there were some. I also helped with experimentally testing it to see if there were actually holes or if the LDPE was just permeable in high temperatures. After we decided to change the basin lining from LDPE, I helped research better alternatives. In addition to the construction, I was very involved with setting the solar still out in the mornings and taking it in at nights. In addition, I stopped by throughout the day to check on it to make sure everything was running smoothly. On a few occasions, after taking the still in for the night, I organized the data gathered throughout the day from the thermocouples mounted on the unit. I was also present for the group meetings where major decisions about our project were discussed and made.

To help myself and our team to get a better understanding of our idea, we visited the Fayetteville bio-solid waste plant. The visit that a few group members and myself made was crucial that how they were treating their waste was very similar to our idea on how to treat the acid rock drainage we were tasked with. In order to gain even further understanding of the properties of acid rock drainage we were having to treat, another group member and I we made the synthetic acid rock drainage solution. We heated it to determine the boiling point of the mixture in addition to determining the temperature the solution would precipitate.

One of my biggest and most important contributions to the project was the research paper. I wrote the technology background research, regulations, safety considerations and public involvement sections of the paper in addition to helping edit it before submitting it. I used other group members research documented in their white papers in addition to my own extended research to complete these sections. Another big contribution was the poster. I did the first iteration of the poster which included summarizing the research paper's information into poster form. I also wrote the safety summary and flow sheet of our bench-scale apparatus. This had to be submitted before arriving at the competition and described our bench-scale operation and process safety.

For the trip to competition, I helped with loading all of our equipment and solar still bench-scale in the truck and trailer. Once we got to the competition I helped to unload all of our equipment and set up our bench-scale apparatus and to make sure we were ready to run it the next day. This included getting necessary materials from the competition coordinators. During the competition, I helped monitor the bench-scale apparatus which included making sure it was operated safely, gathering samples of outlet water and testing the pH. This also included talking with peer reviewers to explain the process of our unit. When the judges came around to judge our poster and bench-scale design, I helped to present and answer their questions. I was very present in helping the four members of our group giving the oral presentation by giving constructional criticism to better their presentation. Lastly, for our team, I was one of the peer reviewers. This consisted of me going around to other tasks' projects and learning about their solution and judging them.

Throughout the course of the design, implementation, and physical presentation of our project, I was very present. My voice can be heard most clearly in my four sections of the research paper, the work in gathering preliminary data and research, poster, and safety and process summary. Every member of our group left their mark on our final product. I believe mine is clearly present as well.