Paper Pulp Sludge Characteristics and Applications

Introduction

A paper mill in the United States Southwest currently produces approximately 40,000 tons of Paper Pulp Sludge (PPS) on a yearly basis. A nearby landfill is operating in a soil deficient environment and uses a fraction of the PPS waste as an alternative daily cover. The landfill accepts PPS at a reduced tipping fee and would suffer financially if forced to bury the excess with incoming municipal solid waste. New uses for PPS are desired by the landfill in order to reduce the amount of material requiring land filling.

Objectives

- Determine specific characteristics of PPS by designing test procedures
- Develop new use for PPS at the landfill

Multidisciplinary Approach

A team of five senior undergraduate environmental engineering students and a senior undergraduate chemistry student worked to complete the project from September 2012 through March 2013. The project managers at the landfill, a licensed environmental engineer and registered geologist, provided information on landfill operations, previously studied characteristics of PPS, and representative leachate composition data. University staff, including five licensed civil and environmental engineers, provided technical support to the students for materials testing, data analysis, and guidance on implementing final designs at the landfill. A PhD chemistry professor at the university provided technical assistance to the team when designing and running custom experiments, and a PhD business professor helped students analyze the financial reality of their final designs. An environmental specialist at the paper mill provided background information on PPS and mill processes. Two outside companies, a metal fabrication shop and a materials testing firm, were subcontracted by the students to aid in project completion.

Paper Pulp Sludge Investigations

The landfill operates in a soil deficient environment and is considering constructing landfill liners and caps made from alternative materials. The goal of investigations was to increase understanding of the material and determine the viability of using PPS in a landfill liner or final cap.

Leachate Interaction

The student team developed leachate interaction testing to determine if virgin PPS could perform as a reactive layer in a landfill liner system. The experiment was designed to quantify the interaction of a mock leachate and PPS. Figure 1 illustrates the batch reaction samples after 72 hours on a shaker table.

Figure 1: Leachate interaction samples

Results from analytical testing on leachate showed anion attenuation, pH buffering, and metal adsorption. In this experiment, conclusive anion attenuation and pH buffering trends were established. Metal adsorption had promising decreasing trends. However, further experimentation is required to determine if PPS can perform as a reactive layer in a landfill liner.

Gas Permeability

Virgin PPS gas permeability testing was conducted to determine the viability of using the material in a landfill cap to retard gas flow. The student team developed test procedures and equipment to model gas flow as laminar groundwater flow. Figure 2 depicts the student team's manufactured gas permeability testing apparatus.

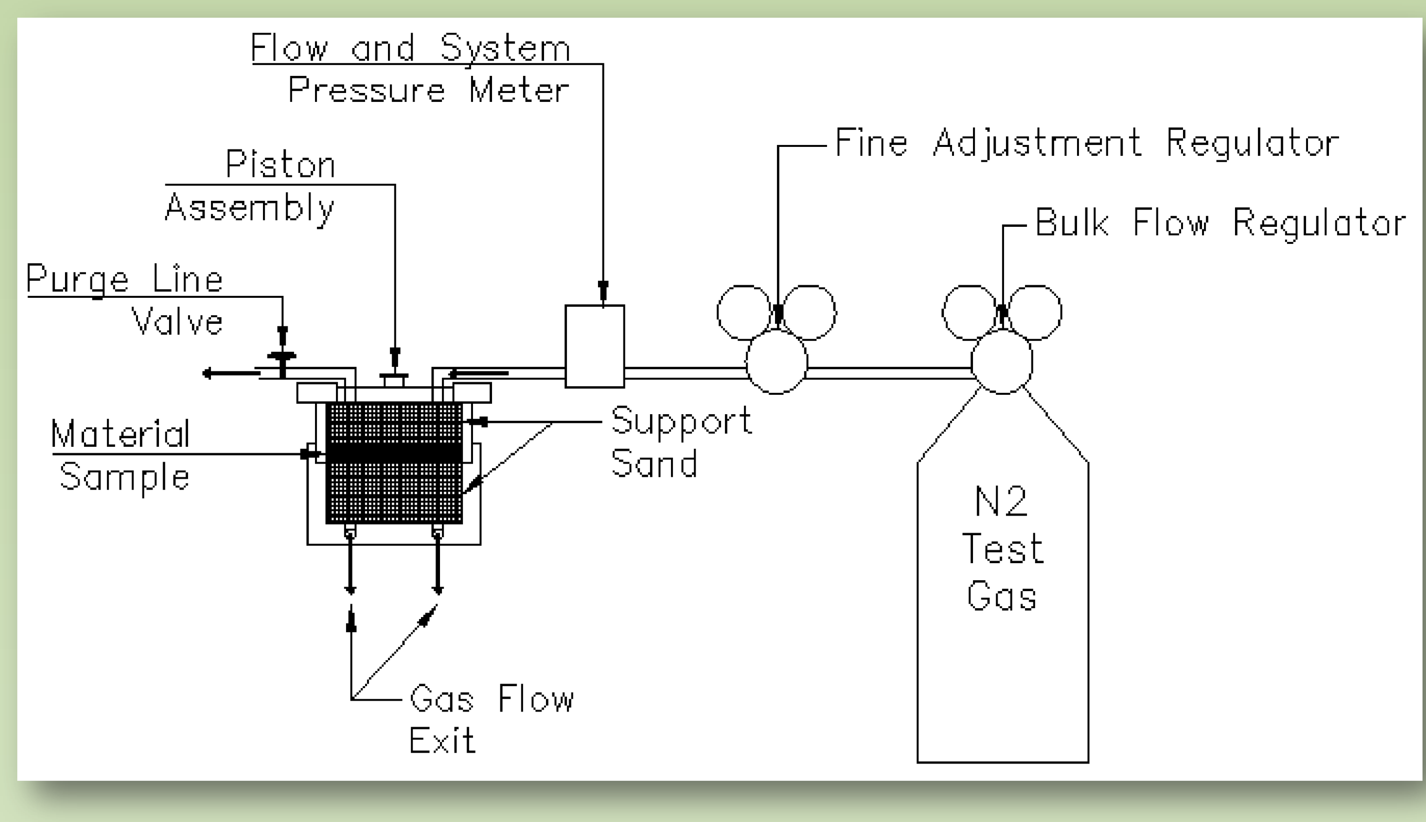

Figure 2: Gas Permeability Testing Apparatus

The results of gas permeability testing on compacted, saturated virgin PPS showed it has a gas permeability of approximately 10^{-5} m/s. A gas permeability of 10^{-9} m/s is typical of cap materials, therefore the student team recommends not relying on virgin PPS to retard gas flow through a landfill cap.

Final Landfill Cap Design

After concluding virgin PPS was not optimal for use as a layer in a final landfill cap/liner, regionally available waste streams were identified for the creation of PPS admixtures. The three materials considered as PPS amendments were coal fly ash, wood ash, and lime. The admixtures were qualitatively and quantitatively evaluated. Based upon results, decision matrices were created to determine the optimal PPS admixtures for use in a landfill cap. Figure 3 illustrates the granular and cohesive admixtures chosen for a final cap design.

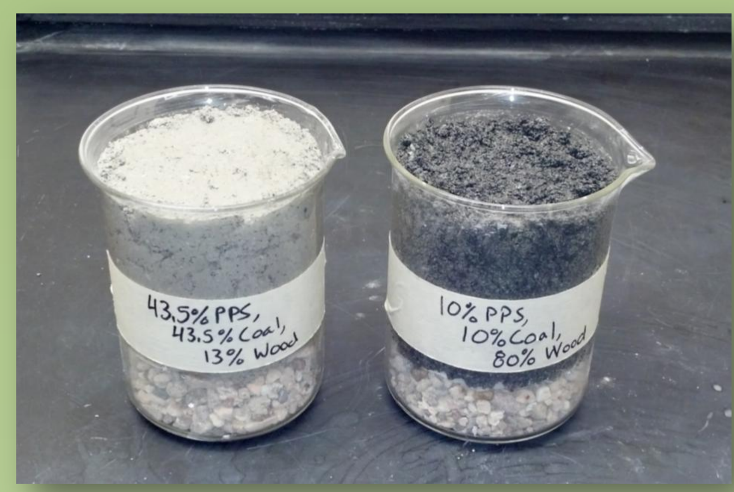

Figure 3: PPS Admixtures

Figure 4 illustrates a profile of the final landfill cap design. The final cap created for the landfill consisted of an erosion layer, random fill layer, drainage layer, and hydraulic barrier layer. In combination, these layers meet all landfill and regulatory requirements. A cohesive PPS admixture (43.5%PPS, 43.5%Coal Fly Ash, 13%Wood Ash) functioned as a hydraulic barrier layer and a granular PPS admixture (80% Wood Ash, 10%PPS, 10% Coal Ash) functioned as a random fill layer.

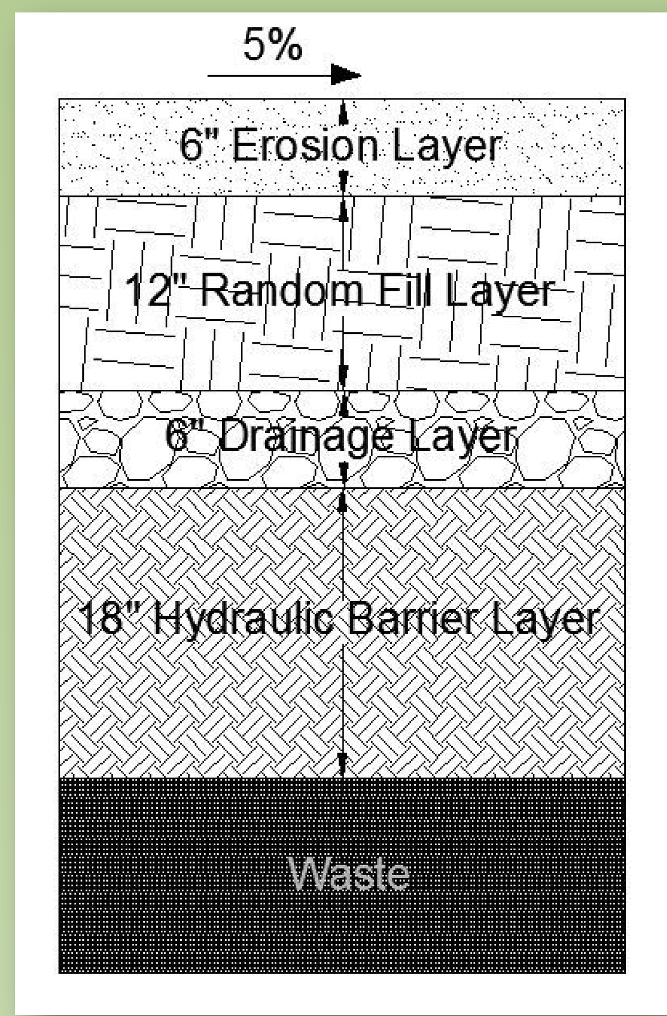

Figure 4: Final Landfill Cap Profile

Conclusion

A final cap design was developed using PPS as a major constituent. A hydraulic barrier layer (43.5% PPS, 43.5% coal ash, 13% wood ash) and random fill layer (80% wood ash, 10% PPS, 10% coal ash) were created for use in the final cap. The cap is expected to meet all landfill and regulatory requirements. In addition, cap materials will cost $8.3 million less per 100 acres than the existing landfill design. A total of 68,000 tons of PPS will be removed from the landfill for use in the cap, increasing the life of the landfill by approximately three quarters of a year.

Paper Pulp Sludge Characteristics and Applications

Abstract

A landfill in the Southwest United States requested an investigation into the characteristics of paper pulp sludge produced a nearby recycling paper mill and the development of new uses for the sludge at the landfill site. A student team comprised of five senior undergraduate environmental engineering students and one senior undergraduate chemistry student accepted the project and completed their work in April, 2013. The student team collaborated with project managers at the landfill, an environmental specialist at the paper mill, and various staff at their university to complete the project. Students subcontracted work when necessary to an outside materials testing firm and metal fabrication shop.

The student team conducted a literature review of the paper sludge to determine a portion of the requested material characteristics. Further laboratory testing was completed for leachate-pulp interaction mechanics, gas permeability, and structural characteristics. Students determined the paper sludge was able to adsorb anions, some cations to a lesser extent, and possessed some pH buffering capacity. Testing further showed the material had gas permeability approximately equal to 2.36 mm to 4.75 mm clean sand. Geotechnical testing indicated the paper sludge had low strength, high water content, and was extremely plastic among other traits

Based on this literature review, material testing, and discussions with the landfill's project managers, a landfill cap was chosen for development. Paper pulp sludge admixtures were created using Class F coal fly ash, wood ash, and lime to produce viable landfill cap materials. Admixtures of class F coal fly ash, wood ash, and paper sludge were combined to create a hydraulic barrier layer (43.5% paper pulp, 43.5% coal ash, 13% wood ash) and random fill layer (80% wood ash, 10% paper pulp, 10% coal ash).

A final cap design was developed based on federal regulations and the needs of the landfill's facility closure plan. Material cost analysis show savings of $8.3 million if the paper pulp sludge based hydraulic barrier and fill materials are used in place of an 60 mil HDPE liner and 2.5 feet of imported soil. Cost savings include freed airspace gained by using 68,000 tons of paper sludge in the cap rather than ultimately burying it with incoming municipal solid waste.

Currently, landfill managers are reviewing the findings and recommendations of the student team. Recommendations include an outlined plan for further testing and final implementation of the cap design. Laboratory testing is recommended to determine if contaminant leaching occurs from the created cap materials. Implementation of the cap can only be completed once local government and state regulatory approval is obtained. Test plots are therefore recommended to be constructed at the Landfill and monitored to determine the performance of the design.

Paper Pulp Sludge Characteristics and Applications

Project Description

Introduction

In 2012, a landfill in the Southwestern United States requested an investigation into the characteristics and possible beneficial uses of a Paper Pulp Sludge (PPS) produced by a local paper mill. The landfill currently uses a portion of the approximately 40,000 tons of PPS created each year for alternative daily cover and is stockpiling the excess with the hope of finding a secondary use for the material. PPS is accepted at a reduced tipping fee to ensure a constant supply for alternative daily cover needs and the landfill would suffer financially if forced to bury the excess with incoming municipal solid waste.

Project managers at the landfill approached undergraduate environmental engineering students at a nearby university for help in solving their problem. The engineering students accepted the challenge and began a multidisciplinary investigation of PPS and possible new uses for the material. They enlisted the help of a chemistry student to aid in material testing, environmental and civil engineering faculty to provide guidance and technical understanding when necessary, a paper mill environmental specialist as a material expert, and business faculty to help evaluate the financial feasibility of developed solutions. Project managers at the landfill continued to support the student-led team throughout the project by providing guidance and feedback at bi-weekly meetings.

Project Summary

Landfill project managers and students collaborated to define the project's scope. The goals of the project were identified as:

- Determine characteristics of PPS produced by the local paper mill
- Develop a new use for PPS at the landfill

Students worked with landfill personnel to identify characteristics of interest to better understand how PPS functioned in a landfill setting. An initial literature review of previous studies supplied by the landfill and paper mill provided information on the hydraulic conductivity, compressibility, and Toxicity Characteristic Leaching Procedure (TCLP) results of PPS.

Further testing conducted by the student group aimed at determining additional structural characteristics of PPS, leachate interaction mechanics, and gas permeability. Geotechnical testing was outsourced by the student group to a local materials testing firm. Results showed the material was highly plastic, able to absorb large amounts of water, and had low strength. Additional leachate interaction and gas permeability testing procedures were created by the student group from a review of recent studies.

In the case of leachate testing, students created an experimental procedure to determine if PPS could behave as a reactive layer in a landfill liner. A member of the college's engineering facility, who earned his PhD by developing adsorption isotherms through similar testing, provided technical guidance on how to structure the tests and analyze final data. A project manager at the landfill who earned his MS studying interactions between leachate and soils provided data on the chemical makeup of leachate at the landfill and guidance on creating a concentrated test solution. After a batch reaction of leachate and various amounts of PPS, the supernatant was analytically tested to determine concentrations of metals and other contaminants. The student team determined that PPS adsorbs nitrate, sulfate, and chloride. Copper, arsenic and lithium displayed promising adsorption trends. PPS was seen to have a pH buffering capacity and leached calcium and magnesium. Additional experimentation is required to determine if PPS can act as a reactive layer in a landfill liner.

Gas permeability testing was conducted to determine if PPS could be used to retard gas flow in a gas capture system. The testing methods were influenced by investigations of geosynthetic clay liners where gas permeability was modeled as laminar groundwater flow (Vangpaisal & Bouazza, 2004). A test chamber was designed by students, in cooperation with a local metal fabrication company, to channel gas through PPS at pressures routinely encountered in landfills. PPS was tested at multiple compactions and moisture contents typical of in-place waste at the landfill, and at complete saturation and high compaction. Data analysis showed PPS did not significantly retard gas flow when compared to clean 2.36 mm to 4.75 mm sand at gas pressures ranging from 0.3 to 1.2 psi.

The student team conducted additional research and met with landfill project managers to determine a viable new use for PPS. Materials similar to the paper mill's recycling waste have previously been investigated for beneficial use by a variety of groups. A study in 1997 found a final landfill cap comprised of paper mill waste blended with water treatment plant sludge performed better in hydraulic conductivity tests than typical clay materials (Moo-Yung & Zimmie, 1997). However, the material was not easily workable, had low shear strength and failed when structurally loaded, and required excessive wetting prior to application. Additional work was completed in 2011 to identify the characteristics of fibrous paper mill sludge in Brazil, and suggested application as a landfill liner as a possible use (Heineck, Consoli & Ibeiro, 2011). Further research into using paper mill waste for slurry wall construction, incineration fuel, or a cement additive has shown these applications are not relevant to the landfill's needs. After discussions with landfill project managers, creating materials useful in constructing a final landfill cap was deemed the most beneficial use of PPS.

A suite of procedures was developed by the student team to create materials and test their usefulness as part of a landfill cap. Several additional large waste streams were identified as possible additives for use in creation of material admixtures. A nearby coal fired power plant produces a fine-powder class F fly ash which is typically combined with lime and used as a concrete additive. The class F ash was investigated for use because it has been shown to have binding and strengthening qualities when combined with soil-like materials and is readily purchasable through a local materials group. Lime was also chosen for consideration as an ingredient as it is typically combined with this class of fly ash to increase binding. A second nearby power plant generates electricity from the combustion of trees and produces a granular wood ash waste. Minimal information was available on the characteristics or possible uses of wood ash. However, it was seen that this material was useful for investigation as it had some of the same strengthening qualities of the class F fly ash and is available for cost of transport.

Eight promising materials, out of 49 total created, were analyzed to act as a hydraulic barrier or support layer in a final landfill cap system. The promising hydraulic barrier materials were tested to determine their plasticity index, gas permeability, liquid permeability, and direct shear and unconfined compressive strengths. Promising support layer materials were tested to determine their direct shear strength. An analysis of required material volumes and costs for each promising material was then conducted and compared to the existing cap plan provided by landfill personnel. After analysis was completed and results for each material compared, hydraulic barrier and support layer materials were chosen for use in a final cap design.

Materials chosen for each layer met the EPA requirements for a landfill cap while providing cost savings over the existing landfill closure plan. The chosen hydraulic barrier material was made of 43.5% PPS, 43.5% coal ash, and 13% wood ash by weight. This material had high shear strength, good plasticity and unconfined compressive strength, and low liquid and gas permeability. A cost comparison between this PPS-based material and the existing landfill plan utilizing an HDPE liner and 18-inches of imported soil showed a savings in material costs of $6.4 million per 100 acres. Further, 57,000 tons of PPS are required to create this material per 100 acres. The support layer material, comprised of 10% PPS, 10% coal ash, and 80% wood ash exhibited high shear strength and desirable mixing characteristics. A 12-inch layer of this support material was estimated to provide $1.9 million in savings per 100 acres over the original imported soil plan. The support layer required over 11,000 tons of PPS per 100 acres, bringing the total amount of PPS diverted from burial with waste to over 68,000 tons or roughly one and a half years of paper mill production.

Current Project Status

Results of PPS testing and cap material creation have been submitted to the landfill project managers for review. Recommendations for the future made by the student team include testing for contaminant migration from each cap material and creating test plots of the final design to monitor long-term performance. Each test plot is recommended to be monitored for consolidation and degradation, liquid permeability, and ability to withstand the harsh Southwestern United States environment. After a review of the student team’s findings landfill personnel will decide the appropriate next step of the project.

Collaboration of faculty, students, and licensed professional engineers

The student team, comprised of five senior environmental engineering students and one senior chemistry student, worked with licensed professionals from the landfill, paper mill, and local university to complete the project. Two landfill project managers, a licensed engineer and a geologist, initially approached members of the student team to develop a solution to the excess PPS at the landfill. The project managers acted as a catalyst for the project and provided necessary background information on the landfill site. Landfill personnel met bi-weekly with the student group to receive updates and provide feedback on the progress of the project.

Specific characteristics of PPS the landfill wanted evaluated were discussed at early meetings, and later meetings focused on defining the criteria for a successful landfill cap design. The registered geologist provided data on leachate characteristics at the landfill and expertise on creating a representative mock leachate solution. In-place waste moisture content was also provided by the geologist. The licensed engineer at the landfill was the primary source for details on the landfill, previous landfill testing of PPS, and requirements for the final cap design. Several studies conducted by the landfill on PPS discussing its performance as an alternative daily cover were supplied along with the results of a literature review conducted in previous years. Design requirements were defined to include meeting EPA landfill closure regulations, meeting site-specific environmental and structural stability needs, using a significant amount of PPS, and having a low cost of implementation. Meetings with the engineer project manager helped the student team to understand what was necessary to implement their idea in the real world.

Students met with an environmental specialist at the paper mill to obtain more information on PPS and the mill processes. The student team, joined by the landfill engineer project manager, participated in a tour of the mill and obtained in-house testing data on the waste. Information on the goals of the project and specifics of PPS characteristics were exchanged between the student team and the paper mill following the initial tour.

When determining how to proceed in laboratory testing, the student team approached seven university engineering staff including five licensed environmental and civil engineers, one environmental engineer in training, and one civil engineer in training. A PhD business professor, PhD chemistry professor, and university laboratory technician were also involved in providing technical expertise to the students. University staff provided technical background information useful in developing standard operating procedures for the leachate interaction and gas permeability studies, choosing structural characteristics to investigate, understanding test data, and evaluating final cap designs for legal and safety issues. The student team approached the environmental engineer in training, who was acting engineering laboratory manager at the university, to help procure testing gasses and other equipment. The business professor aided the students in understanding the real-world financial requirements of implementing their cap design and helped to create a business plan for possible wider adoption. University chemistry staff was helpful in designing testing procedures for leachate interaction studies and running test equipment.

Benefit to public health, safety, and welfare

Landfill caps are designed to protect the general public from the spread of disease and unwanted odors while reducing the production and migration of leachate. Disease is a concern with municipal solid waste due to the large amount of birds and other wildlife which typically frequent a landfill. The cohesive layers developed by the student team provide an adequate barrier to wildlife and reduce the danger of diseases spreading. Further, the low gas permeability of the clay-like hydraulic barrier layer, on the order of 10^{-10} m/s, is expected to reduce the flow of odors from decomposing waste while settling with the landfill over time.

The hydraulic barrier layer also displayed a low hydraulic conductivity of approximately 10^{-7} cm/s at 50 cm of head. A low hydraulic conductivity is necessary to prevent water infiltrating the landfill and forming leachate, a hazardous substance with the ability to migrate out of the landfill and contaminate surrounding groundwater. As the landfill is a grandfathered installation with no liner to prevent the migration of leachate, a cap with a low hydraulic conductivity is necessary to protect the surrounding environment from excess leachate migration.

Multidiscipline and/or Allied Profession Participation

Project completion involved a multidisciplinary team consisting of college students, civil and environmental engineers, an environmental specialist, and experts in the fields of geology, chemistry, and business. The student team itself consisted of not only environmental engineering students but a senior year chemistry student as well. The contributions of the civil and environmental engineering professionals included providing technical expertise in the fields of materials testing and design analysis, information on landfill processes, and guidance on implementing developed cap designs in the real world. The environmental specialist from the paper mill supplied information on plant processes and known PPS characteristics. The geologist landfill project manager and PhD chemistry professor supplied key information used in testing leachate and PPS interaction mechanics. Additional analysis by a PhD business professor allowed the student team to develop a fiscally realistic plan to market and implement their final design.

A local metal fabrication company and a materials testing firm subcontracted by the student team were other key contributors to the project. To finalize gas permeability apparatus designs and construct the final test equipment, students approached an employee at the metal fabrication plant for guidance. This employee was instrumental in constructing the gas permeability testing apparatus which led to successful project completion. Due to the tight project timeframe, the students subcontracted geotechnical testing of virgin PPS to a local materials firm. Members of the firm worked with students to identify which tests were applicable to the project and could be completed within the available time.

Results of this multidisciplinary collaboration allowed the student team to successfully finish their project and deliver a viable final solution to the landfill. The student team chose to also submit their work to the New Mexico State University WERC competition where they were awarded the Freeport-McMoRan Copper and Gold Award for Innovation in Sustainability.

Knowledge or skills gained

The student team increased their knowledge and skills in a wide array of fields. Project management and coordination skills were learned by the student project manager and to a lesser extent all members of the team. Students took the lead on all portions of the project and dictated work trajectory. To coordinate the successful completion of the multi-faceted project, each student was required to take the lead in at least one portion of the work. Management responsibilities such as coordinating meeting times between experts and students, finalizing contracts with outside firms, procuring testing materials in a timely fashion, and developing a timeline for laboratory work were all fulfilled by the student team.

Material testing skills were developed by the students as the project progressed. Students learned how to identify characteristics of interest when examining a material, especially when analyzing how a material functions in a specific setting. Likewise, students learned what characteristics to investigate when creating composite materials. An example is when students used their knowledge that PPS has high amounts of calcium, a binding agent necessary to stabilize Class F fly ash, to remove the need to include lime in final cap admixtures.

Laboratory testing skills and knowledge were increased when students determined applicable standard test methods to use and developed new methods when no standard practices existed. Specific knowledge on leachate interaction testing, gas permeability modeling, and geotechnical testing was gained while developing and running tests. Skills necessary for properly running and managing a laboratory were learned, including procuring materials in a timely fashion and ensuring proper equipment calibration. The students' ability to process laboratory data, achieve meaningful results, and make recommendations on those results, was also increased.

Material creation and analysis skills were increased when the student team developed the final cap design. Students used their new material testing and laboratory skills to create new cap materials and complete performance tests. Analysis of developed materials involved increasing the students' understanding of the requirements of a landfill cap and applying appropriate tests to judge material performance. Specifics knowledge in running liquid permeability, Atterberg limit, unconfined compression, direct shear, and gas permeability tests on clay-like and granular materials was learned during testing.

Knowledge involving the needs and operations of landfills was increased by all students involved in the project. Details on regulatory requirements of landfill caps, the site-specific needs of the landfill, and how landfills operate post-closure were learned by the student team. Knowledge on the monetary operations of landfills, specifically how they run their operations to maintain a positive cash flow, was also gained by members of the student team. Using this increased knowledge, the student team was able to develop a fiscally sound solution to the landfill's excess material problem.

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