

Electrical Resistance Heating for Superfund Site Soil Remediation

A project report for Worcester Polytechnic Institute



Submitted to the faculty of the
Department of Chemical Engineering
Worcester Polytechnic Institute
Worcester, MA 01609

Report prepared by:

Rainier Vaughn

April 27th, 2023

This report represents the work of one or more WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on the web without editorial or peer review.

Abstract

In the United States superfund sites are near marginalized communities, therefore it is essential to include their values and knowledge in the environmental action taken. Undoing the colonial legacy of Francis E. Warren Air Force Base allows a path forward for engineering decisions to be made that include Northern Cheyenne Nation culture, values and communities. Providing educational experiences integrating knowledge of the tribe and promoting research in emerging environmental remediation technologies can allow students to engineer more equitable environmental technologies.

Table of Contents

| | |
|---|-----------|
| Abstract | 1 |
| Table of Contents | 1 |
| Chapter 1: Introduction | 2 |
| Chapter 2: Decolonization and Indigenization of Environmental Remediation. | 4 |
| Introduction | 4 |
| Decolonization | 5 |
| Indigenization | 10 |
| Chapter 3: Lab Report | 15 |
| Introduction | 15 |
| Background | 16 |
| Methodology | 17 |
| Basic Designs | 17 |
| Experimental Procedure | 18 |
| Results | 18 |
| Conclusions and Recommendations | 19 |
| Figures and Tables | 20 |
| References | 23 |

Chapter 1: Introduction

Humanitarian Engineering is the combination of humanities and arts, culture and technology. The Chemical Engineering Department at Worcester Polytechnic Institute (WPI) has applied projects and lessons that align with Humanitarian Engineering principles. By specifically targeting humanitarian principles around colonial legacy, these efforts are refined to provide educational opportunities in the Unit Operations Lab. Although supported by the Department there are challenges that are presented when working to integrate humanitarian engineering into chemical engineering that ultimately highlight the need for these practices.

“These challenges are practical and organizational, but they are also *cultural*: established practices remain so in part because professional identities, disciplinary structures, and organizational and bureaucratic arrangements are interlinked in ways that tend to sustain the status quo. (Skorton, Bear, pg. 95)” In the United States the status quo is built on European American history and often major engineering decisions are made based upon that culture’s status quo. When engineering decisions affect populations outside of this demographic relevant cultures, their values and practices should be included in the decision process. This project aims to support the Northern Cheyenne’s environmental culture where decisions have been made that directly oppose their values.

Previous MQP iterations focused on educational opportunities in middle schools to increase interest in STEM among student groups that historically lost interest because of cultural pressures. Applications of this project can be used in middle schools to achieve similar learning outcomes, but because of WPI Chemical Engineering values and goals, providing more holistic educational opportunities in senior lab classes is a departmental priority. The department values align with “An emerging body of evidence suggests that integration of the arts, humanities, and STEMM fields in higher education is associated with positive learning outcomes that may help students enter the workforce, live enriched lives, and become active and informed members of a modern democracy.” (Skorton, Bear, pg. 4)

The development of an Electrical Resistance Heating Lab Kit support these priorities in two major ways: first, students learn the basics of the technology through a project during sophomore year and through a spiral curriculum the technology will be returned to through hands on education with historical contexts in student's senior year, second humanitarian engineering is the core of potential lessons and allows integration of topics in diversity equity and inclusion.

Chapter 2: Decolonization and Indigenization of Environmental Remediation.

Introduction

The history of U.S. government interaction with the Cheyenne tribes and Native American Nations that once lived boundlessly in southeast Wyoming and the American West is rife with opportunities to decolonize the environmental history of the land. Specifically, the decolonization of U.S. Military presence in Wyoming and its significance to the Cheyenne tribe creates a more holistic understanding of modern systems and techniques of colonialism practiced at the AFB.

Decolonization is the process of undoing the influence of colonialism and the privilege and systems that are built upon it. Decolonization requires a reckoning with the ideologies and powers that settler colonialism ingrained in the people and society of the settler state's colonies. It works towards the achievement of breakdowns of standards, policies, and violence that perpetuate systemic injustices against indigenous communities. Decolonizing environmental remediation is essential in moving forward and providing environmental justice. More than this, once decolonized environmental remediation practices and technologies should be engineered to support indigenous communities. Consultation and collaboration with tribes during the course of a remediation project is the first step in establishing a basis for reparations.

In the case of Francis E. Warren (FEW) Air Force Base (AFB) in Cheyenne, Wyoming, understanding the past and present settler colonialism the AFB perpetuates, is the first step towards decolonizing the authority and agency the AFB has over the land it occupies. Further, collaboration with the Cheyenne tribe, and other native nations who were removed from the land, will begin to focus on indigenized environmental remediation and justice.

Indigenization is the act of amplifying Indigenous leaders, scholarship, and spirituality and in indigenous environmental justice is the ideology that guides environmental policy and remediation. Indigenization of environmental remediation takes on many forms and should affect every

Decolonization

Colonialism is the concept of traveling and setting up colonies in an area to permanently settle people and customs from the original country. Settler colonialism requires both Ideological and physical colonialism. Physical colonialism is usually achieved in part through displacement of Indigenous people, and the United States has a long history of Indigenous displacement for colonial expansion. The F.E. Warren Air Force Base displaced the Cheyenne Tribe in South East Wyoming, and permanently settled the U.S. Military members on stolen land. This was a long and bloody process of displacement and then containment of the Cheyenne by the U.S. Military. The United States practiced ideological colonialism setting up military forts and communities that altered economic, environmental, and cultural practices of Native American nations. This was achieved through policies restricting cultural practices, promoting state violence, and erasure of Native history.

During expansion of the United States frontier in the 19th and 20th centuries, justifications for settler colonialism were founded in Manifest Destiny. Manifest Destiny was the concept that the United States, where only white citizens had full rights, was destined by God to bring ‘civilization’ towards the Pacific. This ideology was a newly formed European-American colonial attitude, and pushed for settlement colonies within the continent. As the United States expanded territories west, it systematically worked to erase Native American people and culture, and the Cheyenne were among those affected.

The Cheyenne tribe can trace its roots to the great lakes region of North America. The Cheyenne were originally stewards of lands along Lake Superior prior to European displacement. As French settlers and fur trappers began to move and extend their trapping excursions deeper into the forests of modern day America and Canada, the Cheyenne and their peers found their tribes faced with new challenges caused by European Colonial and economic interests. Disruption of livelihoods was experienced by tribes all over western North America, and was sparked by the introduction of European Americans diseases, diplomatic practices, and technological expansion. In response to physical and cultural danger, the Cheyenne traveled

west and resettled in the Great Plains of Wyoming, Dakota, and Colorado. The tribe once again encountered European settlers as the American Frontier expanded due to the Louisiana Purchase and land gains from the Mexican American Wars. Cheyenne cultural knowledge and stories have roots in the Great Lakes Region, yet the tribe has adapted with time, integrating their new environment with traditions as they were displaced farther West.

In the 1700/1800s the Cheyenne Nation lived from North Dakota to northern Texas. They interacted with the environment and ecology in a symbiotic relationship. Their economies were based on trading amongst tribes and there was no official currency. As European-American settler colonialism displaced tribal nations farther to the west, the resilient culture and people evolved to become more nomadic, mirroring hunting and farming practices of nearby tribal nations in their new environment. Like in many Indigenous cultures, the Cheyenne practiced cooperative and spiritual land stewardship. Plains Nations interacted with the environment in a more temporary way, emphasizing their more nomadic lifestyle. The Cheyenne people's interactions with the environment were built on relationships between themselves and spirits in the environment. Creation and life came from the land and sustained them and in return respect was practiced for the natural world. Over use of the land, or over consumption of resources was not part of the structure of Native American life.

Westward expansion of the U.S. Manifest Destiny pushed western settlers and economics further into designated Indigenous land, and in turn pushed ideological colonialism throughout the region. The displacement and confinement of Indigenous people to land that is considered less valuable to U.S. settlers is a stark example of the difference in European land ownership compared to Indigenous land stewardship. Land was taken by the U.S., assigned a monetary value, and then was sold to people based on socio-economic status. Prior to this mechanism of land management, Indigenous people lived in harmony with the land, avoiding overconsumption, valuing interconnectedness, and recognizing life in everything around.

FF.E. Warren Air Force base is in Cheyenne, Wyoming as a result of manifest density and American colonialism of the western continent. The continued occupation of the land in Cheyenne, Wyoming from the era of Manifest Destiny in the 1800s to present day established the modern colonial legacy of US Military occupation of traditional tribal lands. Evidence of the power and privilege of the United States' settler colonialism manifests in the rhetoric of settler colonialism, the treatment of the Cheyenne tribe, and treatment of the environment.

The differing environmental ideologies is evident in the two cultures' treatment of the American Buffalo, or Bison. The bison was a critical part of the Cheyenne's food supply, shelter, clothing, and technology, similar to other Indigenous tribes in the region. Bison meat could be dried for long winters and mixed with foraged items. Hides were used for insulation in buildings and clothing. After the introduction of horses to the region, tribes began to hunt in wider ranges. And while this offered more range and more game for the Cheyenne tribe, many of the American Pioneers viewed the tribe's movement as cultural opposition and physically a threat to white settlers on the frontier. "... without their ancient food source, the Indian nations were forced into confinement on remote reservations and succumbed to the next wave of oppressive federal Indian policy, assimilation" (Gilio-Whitaker, 2019, p. 59). During the Era of Manifest Destiny in the 1800s, the European American Settlers hunted Bison close to extinction, reducing the population from millions to just hundreds.

This Bison policy was also systematically enacted by the U.S. Military as physical colonialism in the knowledge that it would cause suffering and population loss to the tribes who relied on them. This had repercussions for both the Native people, but also the ecology of the region. Bison are a keystone species, and the ecology of the region is shaped and defined by their presence and behavior. By endangering the Bison, U.S. settler colonialism drastically altered the ecology of the American West. (Gilio-Whitaker, 2019) By removing a major source for food, shelter, tools, and ritual practices, the Cheyenne tribe had to become in part dependent on the U.S. government to supply themselves. This distinct act of ecological damage and colonialism was caused because of the agency Manifest Destiny gave the U.S. Military.

In comparison to Indigenous environmental values, the European Americans settling along the western frontier of the United States brought ecological devastation and cultural genocide to the region. Land became capital, having monetary value that was divided and sold, a land management practice that did not happen until European-American settler colonialism reached the region. Manifest Destiny pushed Native American communities to reservations on what the U.S. considered less profitable or less resource rich as white pioneers from the East Coast resettled on the stolen land. Soldiers housed at military forts committed violent raids on Native American Tribes in the region, and specifically targeted the Cheyenne.

Settler Colonialism was further established by U.S. policies about Native tribes and treaties between the nations began to create dependent tribal nation states. In 1851 the first Treaty of Fort Laramie was signed between the U.S. Government and the Cheyenne and Arapaho Tribes. This established a large territory spanning the plains Colorado, Nebraska, Kansas, and Wyoming. Notably for the Cheyenne tribe this treaty formally protected the land that is today the city of Cheyenne, Wyoming. Although this territory covers thousands of acres, it reduced the range of land for the tribes and settlement trails passed through land designated for Native American use. It also further removed the Cheyenne from land they had lived with for decades and reduced their freedom of movement. The Cheyenne Tribe was formally removed from the Wyoming territory with the treaty of Fort Wise in 1861 that established the Sand Creek Reservation in South East Colorado. The settler colonial establishment gave monetary value to the land and led to this second treaty reducing the territories allotted to Native Americans. The second Fort Laramie treaty was signed in 1868, just one year after the establishment of the military outpost in Cheyenne, Wyoming. The Cheyenne Nation was not directly affected by this treaty because they had already been displaced by the U.S. Military, but this treaty is a significant effect of physical colonial efforts by the U.S. and removed all remaining tribal Nations from the Cheyenne, Wyoming area.

Massacres against the Cheyenne and other Indigenous tribes scarred the region and U.S. diplomatic connection with tribes. The Sand Creek Massacre was one of the most violent atrocities from the frontier soldiers, who in 1864 executed and pillaged an entire village of Southern Cheyenne and

Arapaho people. Soldiers from the Colorado 1st and 3rd Cavalry Regiments massacred the Cheyenne and Arapaho people after their non-violent surrender on land they were designated to be on. The perpetrators, who were U.S. Army Volunteers acting in the name of the Colorado territory, did not face any criminal repercussions for the massacre of the village.

The Sand Creek Massacre is also an example of ideological differences between Indigenous and European settlement and land ownership. The violence was a distinct example of the colonial violence that was perpetuated as a part of the U.S. Settler Colonialism from Manifest Destiny. This event was a part of a wider effort by the U.S. Military to genocide and capitalize on Native people and land. Intergenerational violence is a symptom of settler colonialism, continuously working to occupy the lands and tribes residing in Colorado, Wyoming, and surrounding states. To white soldiers, land was an extension of individual property to be owned and used, this is the absolute and permanent nature of European ownership. They brought resource-based environmental ideology West with them, and the violence they awarded to the value. The indigenous tribes at Sand Creek had relationship-based environmental practices connected to the land as an extension of the self and guided people through life's seasons, which is a more temporary and cyclical perspective.

Ideological stewardship differences between the cultures was extorted by the U.S. Military and drove the violent displacement of Indigenous people in the region. The Sand Creek Village was in Colorado in 1864 because of a prior treaty that granted them safety to the region they were inhabiting. Hundreds of people from both tribes were displaced and eventually some members of the Cheyenne returned to Wyoming where F.E.W. AFB was officially established decades later. Intergenerational violence is a symptom of settler colonialism, and has present effects on today's Native American agency and community. "The massacre devastated generations of Cheyenne and Arapaho people. The deaths of so many Cheyenne chiefs disrupted tribal governance, and surviving chiefs like Black Kettle lost credibility. Tribes lost much traditional knowledge. Families lost providers. Children lost parents" (NPS Brochure, 2017)

Violent outbursts between Native Tribes and white settlers remained common across the region as the United States of America continued to claim territory from the Cheyenne Tribe. The establishment of the military base in Cheyenne, Wyoming coincided with the forced signing of the Fort Laramie Treaty and Dakota Railroad expansion. Despite these treaties being proposed to avoid violence over land disputes, they were routinely ignored by the U.S. and perpetuated state sanctioned violence against the sovereign Indigenous Nations. The military outpost that evolved into FEWAFB was established in 1867 as an army outpost to protect European-American settlers on western frontier. The purpose of the outpost was to establish military protection to the white Americans moving westward, and their , and their economic and political interests. The chartering of the FEW AFB, which was then a wooden military outpost that housed frontier troops, was a direct result from the economic expansion driven by Manifest Destiny. "When President Lincoln and Congress set plans for the transcontinental railroad, they recognized the need for a military installation to protect Union Pacific workers from hostile Indians" (FEW History) During this era major swaths of territory in the Great Plains, Rocky Mountains, and South West were conquered by the U.S. Military, or by citizens acting with their blessing. The U.S. Military also drastically altered the Wyoming landscape in other ways. When the military outpost was first established, the Bison roamed on open plains. There were very few trees Native to the grasslands and green hills rolled throughout Wyoming. The Military post later in the century began to plant trees in the thousands around the base. The American Military wanted to provide resources and protection to the base by planting these trees, but in the process dramatically altered the ecology of the region. This planting effort began to transform the grassland plains to a forest, impacting native flora fauna of the plains. Even in modern times, the forests that were planted still sprawl around the AirForce Base.

Indigenization

Pollution and environmental contamination is an action promoted by the power of settler colonialism. The detachment of land and nature in settler colonial ideologies leads to physical manifestations of overconsumption, disrespect, disposability and ignorance. Pollution is a very portable

and permanent manifestation. In a decolonized context pollution can be seen as modern state violence to the environment and the people connected to it. Environmental remediation mitigates and removes pollutants and contaminants from soil, water, and air in hopes to restore it to healthy levels.

Superfund sites are locations where the Environmental Protection Agency (EPA) has designated as extremely contaminated and pose a threat to health and safety. Sites receive a superfund designation as established in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Switzer, 1980). The Superfund Program created in CERCLA is a collection of money dedicated to covering costs of scientific testing, reparations to communities, and the cost of chemical cleanup.

Designations under CERCLA provide channels to involve the EPA in project oversight and distribution of funds, to identify liable parties, and to score sights with the Hazard Ranking System (HRS). The ranking system organizes all of the sites identified under CERCLA criteria and scores them according to their risk level and toxicity. An intense screening process is applied to Superfund sites to account for risk to human health and the environment, acute contaminant release and migration, and affected population size. The HRS produces scores between 0-100 and sites that receive a designation higher than 28.5 are added to the National Priorities List (NPL). Sites that are ranked about 28.5 on the NPL have the highest risk to largest populations and high contaminant potency. (1994 p.85)

In 1990 F.E. Warren Air Force Base was added to the NPL with an HRS score of 39.23. This score was given because there are population centers near the affected land and the potential for movement of groundwater contamination. Addition of the site to the NPL allowed for EPA and the Wyoming Department of Environmental Quality (DEQ) oversight to the cleanup proceedings, and required documentation and records of all further proceedings. The Air Force Administration was also involved in the cleanup process as the party responsible for remediation.

Several different technologies were used in the cleanup process at Landfill 5a, and a trial and error process occurred to find an effective technique. When the decision was made to specifically

remediate L5A in 1996, planned remediation techniques using a capping and active gas venting, and recommended that a VOC gas collection system should be used if more remediation is needed in the future. This system would be set up as the fifth installment of the comprehensive remediation of the FEW AFB superfund site.

Project authority is both about legal authority and community agency. Legal authority is held by governments, courts, administrators, and liable parties. Decision power and authority over the land is contractually held by these groups. Community agency is the power the affected community has over public opinion.

There have been numerous superfund sites on Native Reservations in which the overseeing tribe was at the forefront of remediation efforts. F.E.W. is not on Cheyenne reservation land, yet when the systems that led the land to be contaminated are decolonized as above, the significance and relevance of environmental justice to the Northern Cheyenne Nation becomes clear. Indigenization of the environmental remediation of L5A is still possible, with current remediation approaches the project site will not meet acceptable standards until 2050. ERH is a technology that both could potentially decrease project life and restore project authority to Indigenous communities.

In past decisions at the site the Nation has not had project authority therefore, opening avenues of communication and collaboration between overseeing parties is an essential first step in restoring the land to the Northern Cheyenne Nation. Inclusion of the Northern Cheyenne Nation Department of Environmental Protection and Natural Resources (DEPNA) can be established through a Superfund Cooperative Agreement. Superfund Cooperative Agreements establish a path for native tribe involvement, and have been used to allow collaboration between EPA and tribes without tribes having to come up with funding to be involved. This is outlined in a 2007 addition to the CERCLA Act and outlined ways to bring in outside organizations or affected parties into the decision making process. Currently at the F.E.W. AFB a Superfund Cooperation Agreement exists between the Department of Defense and the EPA. The existing agreement is unique to the Department of Defense who has governmental authority over the Air

Force, but a Superfund Cooperative Agreement could be extended to the Northern Cheyenne Nation and other affected native tribes.

Decolonization and indigenization of environmental remediation relies on communication and cooperation between governments. At F.E.W. no tribal authority was consulted in the 1990s. The superfund site is on federal land, occupied by the Air Force, thus the remediation actions and responsibility falls on to the United States Air Force. “The United States Environmental Protection Agency (EPA) and State of Wyoming Department of Environmental Quality (WDEQ), as oversight agencies, concur with the selected remedy. The United States Air Force is the lead agency for the site” (EPA, 1996, p.1) Considering the history of settler colonialism in the capture and development of the land, as well as the removal of tribal nations from the land, the Northern Cheyenne Nation should have been acknowledged and consulted throughout the course of the remediation project. There is a section in each Record of Decision (ROD) for superfund site action that requires identification of cultural significance of the land. Routinely the AFB and overseeing parties ignore the native american tribes historical and cultural significance to the area.

The Northern Cheyenne Tribe’s Administration has outlined its commitment to environmental protection on all levels. Specifically, in recent climate addresses they have also expressed the importance of community involvement and education in our climate future. “...the tribe has been using this project as a training tool to develop energy efficiency and building-retrofitting skills among students and community members while raising community awareness about climate change, renewable energy, and energy efficiency.” This addresses the importance of energy innovation to Northern Cheyenne Nation and the commitment to internal and external work in the community to reduce the impacts of climate change. Interagency efforts have been put forward by the Nation regarding climate action and learning from their project that address energy can lead to the evolution and development of community centered projects that reduce the impact of pollution.

To the Cheyenne tribe, land is sacred and processes that removed and replaced the soil were in direct contradiction to this ideology. ERH is an *in-situ* treatment and requires no removal or transportation of soil. It also offers the opportunity to clean contaminants quicker than current trapping and treating actions. The superfund site is not expected to meet acceptable concentration levels until 2050. ERH projects have a much shorter lifespan ranging in months rather than decades. By keeping the soil intact in its home, and decreasing the project life, ERH can support Indigenous environmental practices. Unattended pollution is a permanent manifestation of settler colonialism that can persist through the environment. The reduction of project life can heal the land quicker and consequently can remove the physical effects of settler colonialism in a shorter time period. Also by remediating contaminant plumes quicker, the risk of groundwater contamination is also reduced. The North Cheyenne Nation lists TCA as one of its top 10 most important pollutants to its environmental policy on groundwater. ERH supports the mitigation of groundwater release much quicker than current remediation action at the superfund site.

As an emerging technology, ERH requires new engineers and operators to support the use of the technology in practical spaces. The opportunity to teach and build interest in STEM to students in the Cheyenne nation can be supplemented by offering education and training on ERH to the community. This in part will build more community agency over the project and allows affected communities to be directly involved in the remediation projects. Educational opportunities with this technology can provide economic support to communities through technical job training, operation in field, and technological development.

Chapter 3: Lab Report

Introduction

The Chemical Engineering department at Worcester Polytechnic Institute is working to highlight humanitarian engineering topics in its course work. Humanitarian Engineering is the practice of intertwining engineering decisions and innovations with social justice. To achieve this integration into the Unit Operations Lab, Electrical Resistance Heating (ERH) technology was chosen to be recreated for use in the lab setting. This technology was studied in a Major Qualifying Project (MQP) by WPI students in 2022. Students designed and built a table top ERH kit that removed ethanol contamination from soil, and created demonstrations for educational purposes (Mungovan and Rylee). In the following project design and experiments the recommendations from the 2022 MQP team acted as a starting point to begin innovating the unit and connecting it to a humanitarian engineering case study.

In the following chapter, the design of a new ERH kit, methodology behind experiments, and subsequent conclusions about the change of contaminant concentrations over time. Data patterns established in prior MQP results of ethanol decontamination will be analyzed and compared to TCA decontamination with the Unit Operations Lab ERH kit.

Experiments conducted in these Potentially could be used to study concentration over time based on changes in operating conditions The goal of this chapter is to provide an overview of the design process for the ERH lab unit. ERH is a relatively new technology and has not been studied as extensively as other soil remediation methods, by recreating the technology in an educational lab setting students can study and apply concepts to an evolving technology that has growing world applications.

Background

Electrical Resistance Heating (ERH) began to be used in industrial remediation solutions in 2005. The system is designed to remove Volatile Organic Compounds (VOCs), and other contaminants from soil that is close to ground water sources because it heats the soil instead of removing it to an off site facility. This reduces contaminant exposure to groundwater by decontamination of the water in the site. This technology is best applied in remediation solutions in which contaminants that are more volatile than water. ERH is an *in-situ* treatment, meaning the reaction and collection of the evaporated contaminant occur underneath the surface. Electrodes are inserted into contaminated soil up to 60 feet below ground. The electrodes are then supplied with electricity and heat the soil to a temperature in which the contaminant becomes volatile, but the water remains. Electrodes arranged in triangles used to slowly heat the soil to remove the more volatile contaminants in the soil. This kind of arrangement is ideal for dumps, spill sites, and wells, because they allow for heat distribution over irregular polygon remediation sites, and do not require particularly rigid components. The extracted air is then brought to the surface and treated.

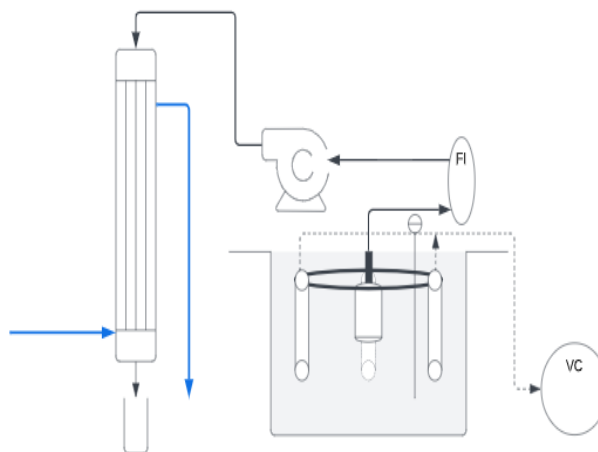
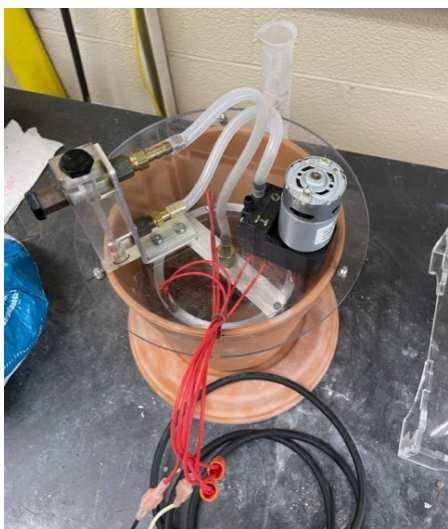
The soil in the ERH lab kit simulated the soil type at the F.E Warren Air Force base and contaminants were chosen to be tested in the lab based on their presence at the superfund site. The soil type in southeast Wyoming consists of about a foot or two of loam, then a deep layer of silty clay, all supported by bedrock beneath. If ERH had been performed on the landfill in Wyoming, the *in-situ* environment would be silty clay, and this composition was recreated for the ERH kit. There are three major soil types that contribute to soil identification, silt, sand, and clay. Different mass compositions correlate to a number of soil types and are referenced in table 1. (Gate 5, 2020, page 5)

Trichloroethane (TCA) was chosen as the simulated contaminant based on two main criteria. First, TCA has chemical properties that make it more volatile than water, and based on our testing concentrations would not fall into a range within the lower explosive limit (LEL) of 5.5% and an upper

explosive limit of (UEL) of 44.4%. This was a relevant discussion because the electricity supplied to electrodes and vacuum pumps posed potential hazards for sparks or overheating. The boiling point of TCA is 64°C. This allows the technology to vacuum the volatilized contaminant without removing the moisture from the soil. Other chemical properties include a molecular weight of 133.4 and vapor pressure of 100 mmHg. Second, this contaminant was present in Landfill 5a at the F.E. Warren Air Force Base, among other notable pollutants, Vinyl Chlorides, and Trichloroethylene. Of the pollutants in the landfill, TCA had significantly fewer health risks, and is safer for students to handle.

Methodology

Basic Designs



The base of the lab kit is a 2 gallon terracotta vessel containing the simulated soil. Capping this is a polycarbonate lid with three fixed aluminum electrodes and a vacuum filter placed into the saturated soil. These electrodes are fixed in an inch radius of the vacuum filter in the center of the vessel. The electrodes were heated with 25 volts of electricity and the power was controlled with a voltmeter. Volatilized gas was pumped through the filter and into a condensing tower where extracted contaminant was then collected. (Mungovan, E.; Rylee, P., 39)

Experimental Procedure

Proof of concept for the unit was established by running three decontamination trials with ethanol as the contaminant. Three trials of about 90 minutes in length were executed and the condensed ethanol extracted from the soil was collected at 10 minute intervals.

Trials were then run to recreate the conditions of LF5A and used TCA as the selected contaminant. Trials began by randomly pouring 3 ml of pure TCA into the moist soil. Similar to proof of concept trials, the goal was to remove TCA from the soil, and condense the extraction stream to be tested by gas chromatography to establish the remediation power of this unit. Samples were collected in 15 ml dram vials every 20 minutes over the course of 80 minutes after the first drop forms. The dram vials were then sealed with a septum cap, to ensure any volatile components remain contained in the sample (Mungovan, E.; Rylee, P., 39).

Other precautions for the ERH kit experiments were taken to assure safety of students, and the containment of any volatile TCA collected. This lab unit has to be operated under a fume hood to collect any escaped gas. Gas chromatography was then used to test concentrations in the extraction stream over time.

Results

Figure 5 shows the gas chromatogram from a pure sample that was placed into the soil. This was then compared to the extracted samples to compare relative abundance of TCA in extraction streams over time. There is a first major peak at 1.5 minutes, this peak had high relative abundance compared to the second peak at 2.05. The first peak could not be identified by the gas chromatography machine with any degree of certainty but the second peak was identified to be TCA with a 98% quality match. The second peak was expected based on the purity of the chemicals used. This peak was expected to be identified in the following sample tests and was the contaminant of interest.

In figures 1-4 spectrum data from gas chromatography does not show presence of TCA in the extracted samples. Further the gas chromatography machine was not able to accurately identify which chemicals were present in the samples. It is important to note that each figure had peaks at the 1.51 minute mark and at the 1.8 minute mark. Neither of the peaks identified correlated with peaks in the pure sample, but they were consistent throughout the samples taken from 0 minutes to 80 minutes. This indicated that the extraction stream was relatively constant. These samples provided internal validation that the unit was extracting volatile compounds consistently but could not be externally validated to the pure sample that was the original contaminant. The relative abundance of the identified peak at 1.51 minutes was highest in sample 1 and as samples progressed with time the abundance of each chemical decreased. This indicated that a bulk of this chemical extraction occurred in the beginning of the trial. The peak that was identified at 1.8 minutes had consistent relative abundance throughout the course of the trial. Based on the changing concentration of the first peak and the stable abundance of the second, it is hypothesized that the first peak is related to the TCA that was used as the contaminant. This cannot be accurately proven by the data and further testing is necessary to identify what chemical this peak contains.

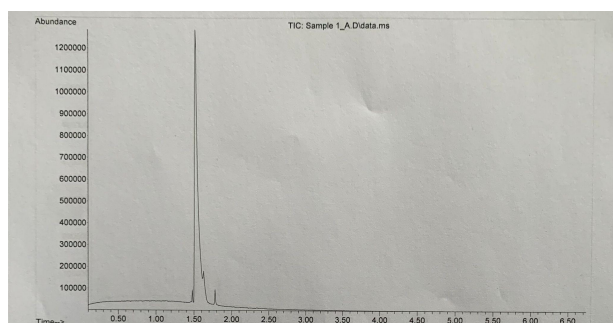


Figure 1:

Gas Chromatography spectrum for sample 1 taken from condensed extraction stream at 0-20 minutes. No TCA was found in this sample.

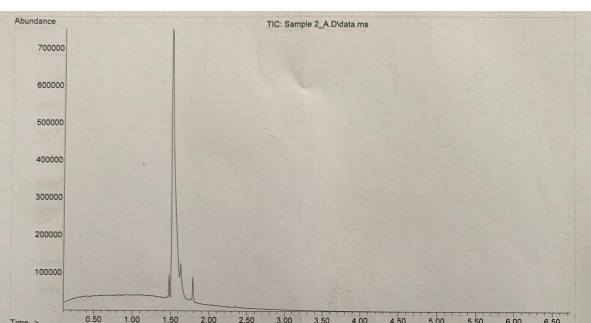


Figure 2:

Gas Chromatography spectrum for sample 2 taken from condensed extraction stream at 21-40 minutes. No TCA was found in this sample.

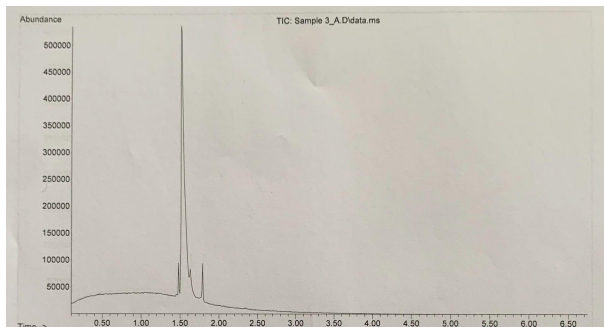


Figure 3:

Gas Chromatography spectrum for sample 3 taken from condensed extraction stream at 41-60 minutes. No TCA was found in this sample.

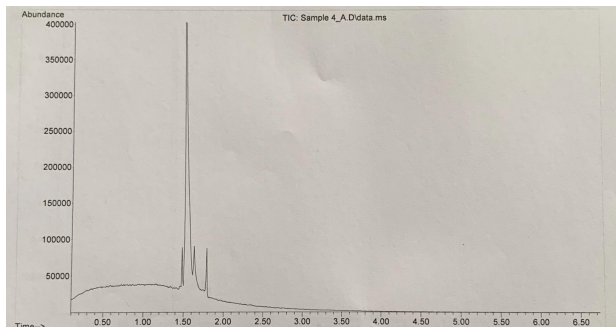


Figure 4:

Gas Chromatography spectrum for sample 4 taken from condensed extraction stream at 61-80 minutes. No TCA was found in this sample.

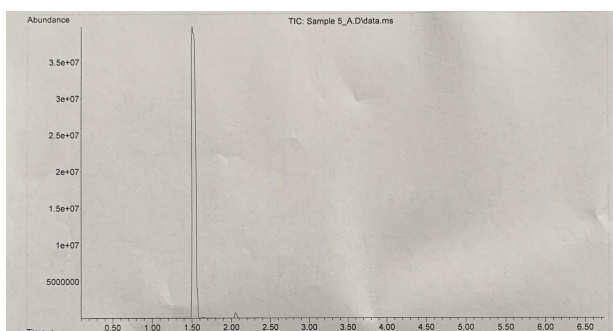


Figure 5:

Gas chromatography pure sample. TCA present at 2.05 minutes.

Conclusions and Recommendations

Ultimately, ERH offers many benefits as a remediation technology, among them a shorter project life, and support for Indigenous practices. This technology offers valuable education opportunities at WPI to have students develop an Indigenized environmental response and test the remediation power of the in lab unit. Future iterations of this project are recommended to collect and test extracted streams to potentially identify TCA in the samples, or identify potential reactions of TCA in the soil that leads to byproducts that can be identified in a gas chromatography machine. Improvements in the Lab Unit should be focused on collecting samples that can be tested in the GC machine or another testing method should be used to identify contents of the extracted stream.

In future projects, research is recommended to study the bioaccumulation of TCA in native prairie plants to quantitatively understand specific chemical persistence in the environment. This can support humanitarian engineering by understanding how clean/hazardous land that has been remediated and returned to its natural state is.

Tables

Tables

| COMPOSITION | MASS (g) | % (mw) |
|-------------|----------|--------|
| Clay | 1200 | 36 |
| Sand | 340 | 10 |
| Silt | 1790 | 53 |

Table 1: Soil composition

| UNIT | TYPE | SIZE | MOC |
|-----------|------------|--------------|-------------|
| E (1,2&3) | Electrodes | 4 in. length | aluminum |
| V1 | Vessel | 1.5 Gal | Terra Cotta |
| V2 | Dram Vial | 15ml | Glass |
| P1 | Pump | 14 SCFH | aluminum |
| C1 | Condenser | | Glass |

Table 2: Operating units and components

| STREAM | PURPOSE | PHASE | TYPE | OC |
|--------|-------------------------------------|---------------------|-----------------------|------|
| 1 | Contaminated air vacuumed from unit | Volatilized TCA gas | Extracted contaminant | 64 C |
| 2 | Pump outlet/condenser feed | Volatilized TCA gas | Extracted contaminant | 64 C |
| 3 | Cooling water inlet stream | liquid | utility | STP |
| 4 | Cooling water outlet stream | liquid | utility | STP |

Table 3: Stream definitions and contents

References

90 CES/CEIEC (Ed.). (2020). *Gate 5 Redevelopment EA Draft*.

F. E. Warren history. (n.d.). F.E. Warren Air Force Base. Retrieved March 3, 2023, from

<https://www.warren.af.mil/About-Us/Fact-Sheets/Display/Article/331281/fe-warren-history/>
[https%3A%2F%2Fwww.warren.af.mil%2FAbout-Us%2FFact-Sheets%2FDisplay%2FArticle%2F331281%2Ffe-warren-history%2F](https://www.warren.af.mil/About-Us/Fact-Sheets/Display/Article/331281/fe-warren-history/)

Final Explanation of Significant Differences (Record of Decision EPA ID: WY5571924179; pp. 1–23). (1998). EPA Superfund .

Gilbert, J., Startin, J. R., & Wallwork, M. A. (1978). Gas Chromatographic Determination of 1,1,1-trichloroethane in Vinyl Chloride Polymers and in Foods. *Journal of Chromatography A*, 160(1), 127–132. [https://doi.org/10.1016/S0021-9673\(00\)91788-6](https://doi.org/10.1016/S0021-9673(00)91788-6)

Gilio-Whitaker, D. (2019). *As Long as Grass Grows: The Indigenous Fight for Environmental Justice, from Colonization to Standing Rock*. Beacon Press.

Kimmerer, R. W. (2020). *Braiding Sweetgrass, Indigenous Wisdom, Scientific Knowledge, and the Teachings of Plants* (Second hardcover edition). Milkweed Editions.

Liboiron. (2021). *Pollution is Colonialism*. Duke University Press.

<https://doi.org/10.1515/9781478021445>

Mungovan, E., & Rylee, P. (2022). *Superfund Site Soil Remediation: Electrical Resistance Heating Kit* [Project Report for Evidence of Completion of a Degree Requirement]. Worcester Polytechnic Institute.

Skorton, D. J., Bear, A., National Academies of Sciences, Engineering, and Medicine (U.S.), National Academies of Sciences, Engineering, and Medicine (U.S.), & National Academies of Sciences, Engineering, and Medicine (U.S.) (Eds.). (2018). *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree*. The National Academies Press.