Superfund Site Soil Remediation: Electrical Resistance Heating Kit

A project report for Worcester Polytechnic Institute

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WPI

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Abstract

This project aims to provide a small-scale learning model to engage students in the cleaning process of Superfund sites. This kit can be used as a demonstration tool in education to provide an interactive learning experience. The kit allows for students at an influential age to understand the dangers of chemicals and their potential environmental impact. This kit can be used by students in middle and high school to spark interest in STEM, while college students can use the model to learn about the engineering techniques used in the electrical resistance heating process. This project looks at the design of an electrical resistance heating kit, which is often used in soil remediation. It shows how to design and test a small-scale kit and shares our results. We also conducted a cost-analysis of the modeling kit to see if it would be feasible to produce this kit for education in classrooms.

Acknowledgments

We would like to thank our advisors, Professor David DiBiasio of the Chemical Engineering Department and Professor Kristin Boudreau of the Humanities and Arts Department, for working closely with us on this project and guiding us through the process. We would also like to thank Ian Anderson and Douglas White for helping us build our design. Finally, we would like to thank the Chemical Engineering Department for providing us with the knowledge, resources, and freedom to complete a project that we are so passionate about.

Executive Summary

Introduction

A Superfund site is an area in which the United States Environmental Protection Agency (EPA) has identified as a hazardous waste site. There are currently over 1,300 Superfund sites scattered across the United States. Improper chemical disposal is a problem that affects not only the environment, but the people living in these communities. Superfund sites have been linked to adverse health effects including infant mortality, mental health, water and food-borne illness, and cancer. In fact, living near a Superfund site shortens the average lifespan of the members of the neighborhood by 1.2 years (Taylor & Bramhall, 2022). It is absolutely imperative to educate people about the dangers these sites impose, before irreversible damage occurs. The goal of this project is to educate students about the dangers of Superfund sites and the importance of cleaning existing hazardous sites, while preventing others from developing.

In order to educate about the dangers of improper chemical disposal, this project aims to create an interactive Superfund site model to exemplify the remediation process of these contaminated lands. The objective of the model is to engage students in the remediation process, which will teach them the importance of proper chemical disposal to make a future impact in their career and the world.

As the consequences of chemical contamination are communicated to our audience, we hope that students will take what they learn and apply it to their futures. Ultimately, we hope that this will inspire students to explore a future in STEM, as well as a lesson they could carry on to share with others. Whether students become managers in companies or pursue a STEM career, they will remember this learning experience and make decisions with the company's environmental impact in mind.

Results and Discussion

To educate our audience about Superfund sites, we created a small-scale model of a contamination site akin to one you would see in real-world situations. There are many different methods that the EPA uses to clean these contaminated areas, but we chose electrical resistance heating. Electrical resistance heating (ERH) is a method of soil remediation where the soil is heated in order to vaporize the volatile contaminants in the soil, and the vapors are sucked from the soil using vacuum units. By demonstrating how Superfund sites are cleaned using ERH, students are able to explore topics such as heat transfer, mass transfer, and thermodynamics.

We started this task by first developing a sketch of what we thought the model would need to completely clean contaminated soil, and with the help of the machinists in the chemistry department, they were able to make the drawing a reality. From the machinists, we received two models: a mock acrylic unit and the final electrical resistance heating prototype.

Through several trials with our model using varying amounts of our chosen contaminant, ethanol, we found our design to completely remove all of the chemical from the soil. We tested the vapors collected from the system through gas chromatography, which was able to detect whether or not ethanol was present in the injected sample. We knew the soil was completely clean of ethanol when no peaks were detected in the plots given by the gas chromatograph. This was confirmed by moving the heating rods throughout the soil and no peaks were detected by the gas chromatograph.

By combining science, history, legislation, and the humanitarian impact this project has, we have encompassed many subjects into learning about Superfund sites to make it most engaging for students at the secondary school and college levels.

Conclusion and Recommendations

The electrical resistance heating soil remediation model that we developed effectively removed all of the chemical contaminant that we added to the soil. The model we produced can be used in secondary school classrooms and in college labs alike. The model is simple enough where the audience doesn’t need an engineering background to understand how it works, but complex enough that it proposes principles of heat and mass transfer, as well as thermodynamics, for college students to explore. This project effectively combines topics in history, law, and science to allow for an engaging learning experience which creates a more scientifically-literate population in the future. The kit is also cost effective, where it would take a projected $150 to reproduce the model.

For further testing, we would recommend finding the largest range of distance the heating rods may be from each other to effectively clean the soil in the system. Another suggestion would be to find if there are any other relatively safe, volatile compounds that could be added to the soil to repeat the process to see if it is still effective. The system could also be saturated with salt water instead of cold tap water to measure the effect that the salt has on the conductivity of the heat in the system.

Background

In order to educate against the dangers of Superfund sites, it was necessary to first investigate the origins of the Environmental Protection Agency (EPA), and how it birthed the Superfund program. We then explored several historic sites that had an impact on the Superfund program and legislation today. We ended our research by investigating how these sites are cleaned and how to educate the growing youth of the problems Superfund sites present.

What is the EPA?

The Environmental Protection Agency (EPA) was first established in 1970 by President Richard Nixon. Concerns about the environment began in the 1960's with awareness about the Earth's limited natural resources and the need to protect them (2021). Images and reports of rivers spontaneously combusting, spilled oil washing up on beaches, and waste being dumped into the Great Lakes prompted President Richard Nixon's 37-point message on the environment presented to the House and the Senate in early 1970. Following recommendations and deliberation, the EPA was formed (2021).

The EPA's primary mission is to "protect human health and the environment" (2021). This agency ensures that Americans have clean air, land and water. It reduces environmental risks by using federal law to protect human health and the environment. It provides access to accurate information to all parts of the community so they are aware of risks (2021). It also reviews the safety of chemicals in the marketplace. One large part of the EPA is its efforts in ensuring responsible parties clean contaminated lands and toxic sites (2021). This responsibility of the EPA is what we will be focusing on throughout this project.

What is a Superfund Site?

A Superfund site is a plot of land that has been contaminated by toxic chemicals due to improper management, improper storage, or improper disposal (2021). These sites are often old chemical dump sites, landfills, old manufacturing facilities, or sections of waterways that chemicals have leaked into. The National Priorities List (NPL) is a national list of sites that the Environmental Protection Agency (EPA) has prioritized to be cleaned based on the hazardous substances in the site (2021). As of 2021, around 1,300 Superfund sites in the United States were on the NPL, most of which are in New Jersey (Tiseo, 2021). Many sites have been cleaned since the beginning of the Superfund program; however, there are still many that remain to be cleaned.

Below we highlight several Superfund sites of significant importance in either the push for Superfund site legislation or pose ongoing concerns since the Superfund program was implemented. The site in Love Canal, New York was the catalyst for the Superfund program introduced by the EPA. The DuPont facility in West Virginia exemplifies a company's lack of care that damaged a whole community. At the CTS of Asheville Superfund site, multiple companies contributed to the contamination of a plot of land over many years that EPA failed to investigate, resulting in significant damage that might have been avoided if testing of the site was handled properly. Camp Lejeune, a recent example of a contamination site, shows that chemical dumping and improper chemical disposal are still very relevant and dangerous, even with all of the EPA regulations in place. All of these examples exemplify the true dangers and tragedies that communities face due to improper chemical dumping, disposal, and lack of care from authorities. In most, if not all of these cases, the true danger of the chemicals contaminating the land was known, but was not shared with the public.

Love Canal

A three-block tract of land that William T. Love bought in Niagara Falls, New York was initially designed to be a canal connecting the higher and lower sections of the Niagara River and to generate power for the proposed city. In 1910, the project ultimately failed due to changes in the economy and other technological advances (Beck, 2016). A ditch was the only thing that remained, which was later turned into a chemical dumpsite. In 1953, Hooker Chemical covered the dumpsite with dirt and sold it to the city for one dollar. In the following years, a town was built on that site and there appeared to be no problems. On August 1st, 1978 this front-page article in the New York Times started with this paragraph,

> *NIAGARA FALLS, N.Y.--Twenty five years after the Hooker Chemical Company stopped using the Love Canal here as an industrial dump, 82 different compounds, 11 of them suspected carcinogens, have been percolating upward through the soil, their drum containers rotting and leaching their contents into the backyards and basements of 100 homes and a public school built on the banks of the canal (Beck, 2016).*

A record amount of rainfall triggered leaching of chemicals through their underground drums. Love Canal was visibly in turmoil, as chemical puddles and rotted chemical drums riddled the ground, and the habitat around it suffered. The residents of Love Canal were also feeling the effects. Children were getting burns on their hands and feet as they played in their backyards, the air was heavy, and mothers were having miscarriages and children born with birth defects (Beck, 2016).

The residents of Love Canal faced a huge struggle. The residents felt powerless, they were living in an area that was negatively affecting their health, while dealing with an indifferent government. The Love Canal residents gave a huge push to move out of the area due to the hazardous conditions. Unfortunately, many residents were too poor to move and the government was not willing to relocate families. After increased efforts by the residents to be relocated, only some of the families were rehomed, but most remained in Love Canal. After visits by the EPA to Love Canal, nothing was done (1997). Eventually, the Love Canal Homeowners Association, created and led by Lois Gibbs, took three members of the EPA hostage demanding the residents be relocated. The residents believed that if they were forced to live there and told it was safe, members of the EPA should also stay there. After 6 hours they let the men go, but gave the President four days to help them, or else. Finally, after three long years of the residents fighting, President Jimmy Carter declared a national state of emergency and relocated the community. Even though eventually Love Canal residents won the battle, the long-term health effects would remain. This tragedy was the beginning of the Superfund program (1997). Due to the tragic events at Love Canal, it was the first time government funds were used for something that was not a natural disaster. The site was eventually cleaned and was removed from the NPL.

Figure 1. An abandoned home in Love Canal after the disaster (Picasa, 2018).

Lois Gibbs played a very important role in the awareness of Superfund sites. Lois Gibbs started investigating Love Canal due to rising health concerns in her child. She noticed patterns with other families and children in the area and eventually discovered that Love Canal was a chemical dumpsite. Gibbs worked hard to educate the community and determine the impacts on their health because of these toxic chemicals. It is because of Lois Gibbs, the efforts of the Love Canal community, and the Love Canal tragedy, that the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 was passed (n.d).

DuPont Teflon Toxin

In 1951, DuPont in Parkersburg, West Virginia began to manufacture Teflon, a chemical coating first used as a spray for non-stick pans and later on incouches, popcorn bags, and even clothing. Teflon is a type of C8, which is a perfluorooctanoic acid (PFAO). Perfluorooctanoic acid is a type of synthetic, toxic chemical, which is a possible carcinogen. PFAOs are forever chemicals, which means they do not naturally disintegrate in the environment. Everyone had some kind of Teflon product in their homes. As the demand for DuPont's Teflon rose, an increasing number of employees worked in the plant to produce their supply.

In 1954, DuPont became aware of C8's possible toxicity. By 1961, DuPont researchers confirmed that C8 is toxic. Simultaneously, the demand for Teflon-coated pans and their repelling characteristics were rising. By 1970, DuPont scientists confirmed that PFAS are highly toxic when inhaled. It was only in 1981 when female workers were reassigned, after studies showed that PFAS damaged animal fetuses. Throughout this time, women that worked with the PFOAs at DuPont gave birth to babies with physical and mental disabilities and deformities. Men suffered from testicular cancer and prostate cancer.

Figure 2. This is an image of the DuPont facility responsible for the disaster in Parkersburg, West Virginia (Rich, 2016).

As studies on C8's toxicity continued, the results were grave. According to a study of 70,000 people in 2007, C8 was found in 99.7% of Americans blood (Sisk, 2021). According to Chemical Watch in 2018, since C8 is a forever chemical, it has even been found in the blood of polar bears in the Arctic. In one study, after Teflon was heated and released through the vents in a lab, a flock of birds flying overhead all dropped dead. Studies done on rats who were exposed to Teflon resulted in birth defects to their eyes. Downstream from DuPont in 1999, cows and animals at a farm not far from the plant started dying. A video recording showed bubbly green water coming from a pipe at the DuPont plant, which led straight into the stream that the cattle drink from. The owners of the farm then died of cancer in the following years.

It soon became apparent that DuPont was aware of the dangers that C8 produced, but denied the extent in order to save face and avoid financial ruin. In 1978, when 3M reported that there were traces of C8 in the employees' blood, DuPont claimed they were "disturbed," but this information was kept inside of the company. In 1980, C8 was proven by 3M to be toxic to rats and monkeys, and DuPont began to sample their employees' blood for their own studies for C8. In 1982, DuPont conducted a study where they did not find birth defects in rats that were exposed to Teflon, contradicting a previous 3M study. At this point, DuPont ordered all women of child-bearing age back into the factory. Although DuPont was aware of C8's possible toxicity since 1954, and its confirmed toxicity in 1961, it wasn't until 2002 when the EPA initiated a priority review of the chemical. Even then, the EPA, the state of West Virginia, and independent studies argued over what concentration is harmful to humans. In 2004, DuPont settled its class-action lawsuit with over 80,000 plaintiffs for $343 million. The EPA ended up fining DuPont $16.5 million dollars for failure to report these risks. The site in Parkersburg in 1991 installed a french drain-type seepage collection system in order to capture the contaminated water. This water then passed through an activated carbon treatment system, and released into the Ohio River (EPA, 2015). Eventually, DuPont created a spin-off company called Chemours, which took over the development of fluorochemicals. Fluorochemicals are forever chemicals, and are only one of the 88,000 unregulated chemicals used in everyday products. Chemours is now the largest producer of fluorochemicals in the world. As part of the settlement, DuPont promised C8 would be phased out of use by 2015, however, it seems that the damage has already been done.

CTS of Asheville

Figure 3. The CTS of Asheville site (2017).

The CTS of Asheville Superfund site was a horrible tragedy in Asheville, North Carolina. The International Resistance Company, which made electrical components, owned and occupied the site for seven years starting in 1952. After the International Resistance Company owned the land, they sold it to the CTS Corporation, who also produced electrical components on the site for the following 27 years. In 1987, CTS Corporation sold the site to Mills Gap Road Associates, who in turn sold part of the land to Biltmore Group, LLC in 1997. Biltmore Group developed their almost 45 acres into a residential area. The site of the old factory was fenced in and remained vacant (2017).

In 1990, the EPA hired NUS, a testing company, to test the Asheville site for toxic chemicals. NUS tested different areas around the Asheville site and near the Rice family property, a nearby family. The test results came back positive for dichloroethane (DCE) and vinyl chloride which mean there is most likely trichloroethylene (TCE) nearby. These chemicals are known carcinogens, which can cause cancer and other serious health problems (2017). Since it was probable that TCE was present, NUS did additional testing on the water near the Rice family property and discovered very high levels of DCE and TCE. Even with all this testing, neither the EPA nor NUS notified the Rice family or any other residents in the area. Nothing was done with this site for years and it remained untouched (2017).

As time went on, more and more of the residents noticed serious health problems among them. Many individuals in the surrounding community were affected, “some are battling cancer and other terminal illnesses they say was caused by exposure to toxic chemicals like trichloroethylene, or TCE,” (Person, 2013). The Rice family started to suspect something was wrong with their drinking water. They tried contacting the state thinking things would be taken care of, but it was not. In 1990, the Rice family discovered that their well water was contaminated. The Rice family was not initially aware, but they discovered that the EPA did know and did nothing about it.

Additionally back in 1980, it was discovered that CTS admitted to disposing hazardous waste off-site, making the EPA establish the Asheville area as a Superfund site. Then, CTS submitted a report saying no one lived close enough to the facility and everyone used city water, so there was no potential danger. The EPA did nothing to fact check this assessment and moved the Asheville site to low priority. The EPA made mistake after mistake failing to acknowledge the individuals with private wells living within 1,000 feet of the site (2017). The EPA even went as far as to remove Asheville from the National Priorities List because they stated that everyone was safe. It was not until 1999, 40 years after CTS first arrived at the site, that the residents were notified of the contaminated water. The EPA quickly issued an emergency action memo. The EPA issued a strict warning to the Rice and Robinson family, who also lived nearby. The EPA officials told them, "The water is very dangerous; you're not to drink it. You're not to bathe in it, you're not to wash clothes in it, wash dishes in it, it's very dangerous," (2017). These families had been drinking this water for years. The families were outraged, since it was very likely that their health problems had been caused by the contaminants in the water. In 2012, the residents finally learned the truth about the testing that had been done by the EPA and had hidden from them (2017).

These families suffered for years and were left with countless health issues that will affect them the rest of their lives. The EPA hid the truth from the residents and made Asheville not only a tragic story, but a story with multiple injustices. In 2006, a soil vapor extraction system (SVE) was used to vacuum volatile organic compounds (VOCs) from the soil (2017). Approximately 6,473 pounds of VOCs were removed using the SVE system. From 2017 to 2018, electrical resistance heating (ERH) was used to clean a 1.2 acre section. ERH removed approximately 5,600 pounds of TCE and 12,000 gallons of NAPL from that section. Today, some site clean-up is still being done in hopes of eventually removing Asheville from the list of Superfund sites (2017).

Camp Lejeune

Camp Lejeune, a military base in Jacksonville, North Carolina, has been described as "the worst example of water contamination this country has ever seen." The recorded levels of contaminant, noted as "methyl-ethyl death" in the soil by federal investigators were among the most concentrated that have ever been measured.

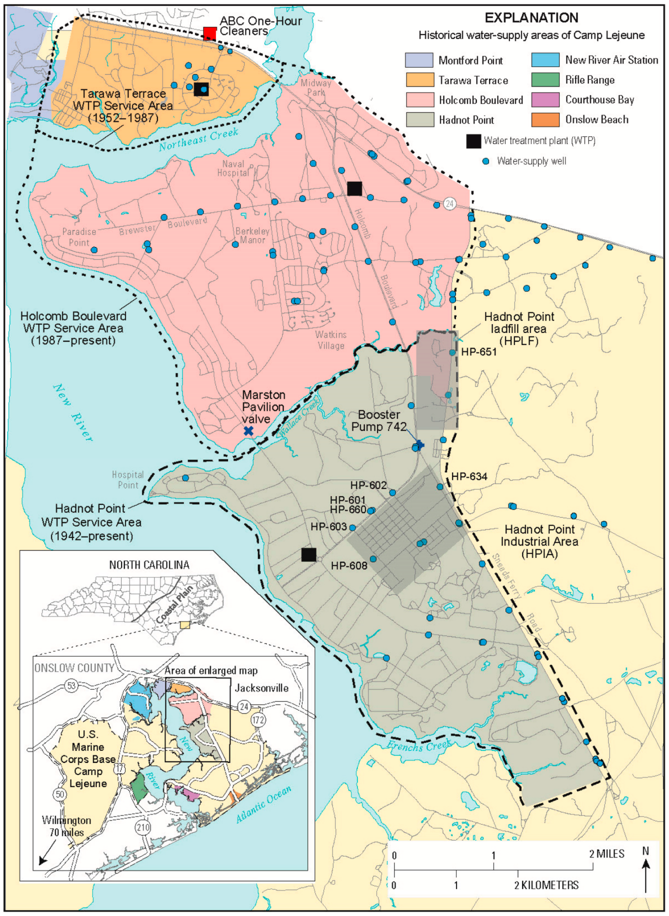


Figure 4. Camp Lejeune contaminated water site (Aral, Bove, F. J., M. M., Maslia, M. L., & Ruckart, P. Z., 2016).

Camp Lejeune was home to members of the military and their families. In this case, Camp Lejeune was a place in which the country they were serving was simultaneously poisoning them. Countless children born to these families on the base suffered from cancer in their adolescence. There had been so many miscarriages, still births, and deaths of young children that the local cemetary was renamed “Baby Heaven.” Men on the base suffered higher than average rates of breast cancer from drinking the water.

In 1981, officials at the base were notified that the drinking water on the base was contaminated with “methyl-ethyl death” which is known to toxicologists as a variety of known carcinogens. However, the first batch of groundwater wells were not shut down until late 1984. The base eventually became a Superfund site in 1989. In the decade before Camp Lejeune’s construction, a chemical plant used safety solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE). TCE and PCE were saturated throughout the ground in Camp Lejeune and into the aquifer. Benzene had also been flowing through the soil from deposits from the Hadnot Point fuel farm.

The Superfund law passed in 1980 did not apply to federal facilities until 1986 (Nazaryan, 2014). Lejeune is only one of the many contaminated military bases throughout the country. Until late 1988, about 1,500 gallons of fuel were estimated to be leaking each month, totalling more than 1.1 million gallons of leaked fuel from the underground tanks. It was not until 2011 when the EPA released the dangers of TCE, however, there had been data to prove it was cancerous as early as 1990. The site eventually began its cleaning process in 1992 by the Navy via installation of a groundwater treatment system and a bio-treatment cell for contaminated soil. In 2001, the Navy utilized electrical resistance heating to treat the site. Cleaning of the groundwater at the site will continue through 2022 (EPA, 2017).

Legislation in Superfund History

According to the EPA, in 1976 in response to public concern of “midnight dumping” of harmful waste, Congress imposed the Resource Conservation and Recovery Act (RCRA). This would allow for controls to be set over the removal and disposal of hazardous waste. In the same year, the Toxic Substances Control Act (TSCA) was enacted by Congress to give authority to the EPA to protect public health and environment. In 1978, Niagara Falls, New York was declared a State of Emergency by President Carter after a rise in birth defects at Love Canal. Lois Gibbs and the Love Canal community raised awareness about the dangerous unregulated dumping of hazardous waste in communities. By 1979, the House and Senate came together for hearings about the dangers of dumping hazardous chemicals. Major bills were introduced to create a “superfund” to deal with this environmental danger by both committees.

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund. This act addresses the dangers of these unregulated hazardous wastes through the development of nationwide programs for emergency response, information gathering and analysis, liability for responsible parties, and site cleanup. It also creates a “superfund” (or a trust fund) of money that would finance these national programs. The first site that “superfund” successfully remediated was “Valley of the Drums” in 1981 in Kentucky by safely removing all toxic waste.

Superfund legislation, which provided funds to clean up toxic sites and instated penalties to discourage contamination in the first place, was only the first step in achieving environmental justice. A landfill protest of 1982 in Warren County, North Carolina started the concern of an unequal distribution of contamination in minority and low income neighborhoods. This became known as the birth of the environmental justice movement. People began to recognize how the environmental disasters tended to disproportionately affect disadvantaged communities. Figure 5 below demonstrates the correlation between the number of drinking water violations and the populations of color. There is the most amount of drinking water violations in places with a large population of color, which proves the above point.

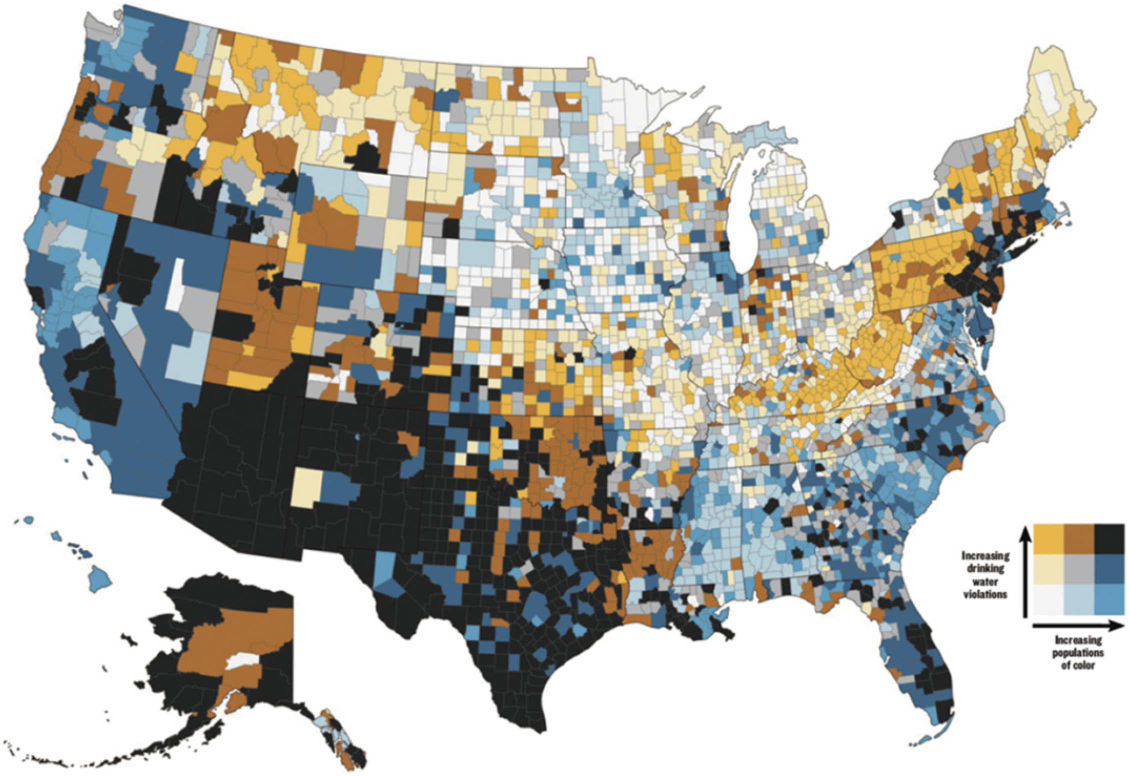


Figure 5. A map of increasing drinking water violations with respect to increasing populations of color (Ensia, 2020).

The EPA created the National Priorities List (NPL) in 1983, which used a screening system to classify environmental disaster sites. This list noted the sites eligible for long-term remediation actions that can be funded through the Superfund program. The Friedman Property site in New Jersey became the first site removed from the NPL in 1986. In 1990, the Oil

Pollution Act was introduced by Congress, which established a tax-based compensation trust fund, while making the costs associated with pollution cleanup the responsibility of the oil handling industry. Following the Oil Pollution Act in 1990 was the Pollution Prevention Act. The Pollution Prevention Act was passed by Congress to establish pollution prevention as a national policy. This encouraged industries to devise technology and enforce protocols to avoid the use of hazardous substances.

In 2014, Obama proposed a budget with a decrease in the EPA's budget by $310 million. However, the decrease in funding offered a $67.8 million increase from the 2014 budget to Superfund programs. In response to the rise in Superfund funding, a comprehensive review was done to evaluate the efficiency of the cleanup model currently followed. The review was used to ensure effective cleanup techniques and to protect human and environmental health. The Superfund Task Force was established in 2017 to provide recommendations to improve and make remediation processes more efficient. This task force operated on the following five goals: expediting cleanup and remediation, reinvigorating responsible-party cleanup and reuse, encouraging private investment, promoting redevelopment and community revitalization, and engaging partners and stakeholders.

All of this legislation has led to where we are in the present day. Through the passing of these legislations, these laws aim to reduce the amount of contaminants released by companies into the environment, and encourage safe and clean disposal. These laws have made the environment significantly cleaner than without, and less people and communities are affected by illegal chemical dumping (EPA, n.d.). As these sites are cleaned, the environment undergoes ecological revitalization. This means that the species living in this area are about to flourish again, which also allows for the property to regain its value. These restored lands also allow for increased tourism, tax revenues, and promote healthy lifestyles with improved air quality.

Soil Remediation Techniques

Our proposed educational component focuses on soil remediation techniques. All the Superfund sites described above are primary examples of soil contamination. We decided to focus on soil remediation throughout this project because soil contamination is often the first step in toxification. Chemicals leach into the soil, which can then seep into groundwater, which may lead to creeks, rivers and streams. Once the chemicals reach water sources, they can be carried far and more freely, creating a dangerous reach of toxicity from the originated chemical accident. We wanted to find a way to address the chemicals before they would travel farther than their initial contamination site. We are most interested in the in-situ techniques of soil remediation, more specifically, electrical resistance heating.

There are two types of soil remediation techniques, in-situ and ex-situ. In-situ remediation means that actions are taken on-site to remediate the contaminated soil, while ex-situ remediation involves the treatment of soil away from the contaminated site. Depending on the type of contaminant and the site, different remediation techniques prove to be more effective than others. Therefore, the type of remediation a site will use is chosen on a case-by-case basis.

In-situ

Within in-situ remediation, four common techniques are used to remediate contaminated soil on-site, including chemical oxidation, augmented microbial enhancement, aeration, and soil blending (n.d.).

Chemical oxidation involves a process of mixing chemical oxidants with the contaminated soil in order for the chemical oxidants to react with the contaminants in the soil. Iron agents are injected into the soil along with hydrogen peroxide, which helps break down petroleum contaminants. Augmented microbial enhancement is a process where microbial organisms are introduced into the contaminated soil. The microbes would then break down certain chemicals using their natural digestive processes, remediating the soil and rendering the soil neutral. Aeration remediates hydrocarbon-contaminated soil by interacting oxygen with the hydrocarbons buried deep within the soil, which initiates and speeds the natural biodegradation of the contaminants. Soil blending works by lowering the concentration of contaminants in the soil by introducing uncontaminated soil to the site. By mixing both contaminated and uncontaminated soils, the concentration of the contaminants is lowered greatly.

An additional type of in-situ soil remediation is through the thermal treatment technology of electrical resistance heating (ERH). Electrical resistance heating works through the addition of heat to the soil, followed by removal of the vapors, which decreases the concentration of volatile contaminants in the ground (2006).

Ex-situ

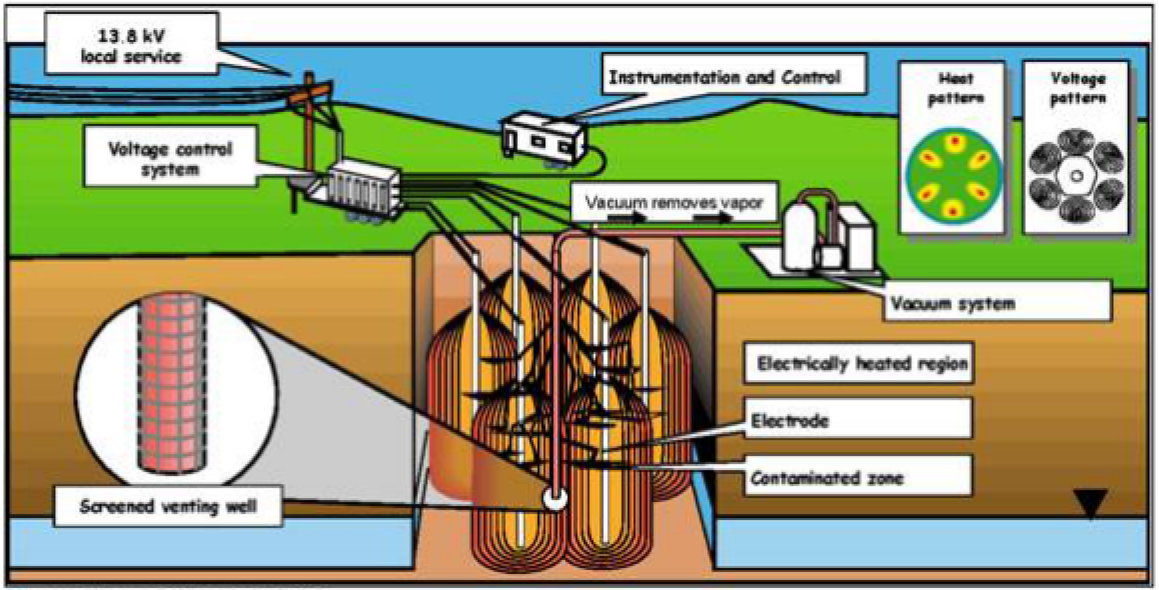
One of the advantages of ex-situ soil remediation is that it takes less time than in-situ soil treatment and offers more certainty about the concentration of the contaminants in the soil. Common technologies used in ex-situ remediation include land farming, soil washing, composting, bioreactor, ion exchange, adsorption/absorption, pyrolysis, and ultrasound technology. Ex-situ remediation technologies are often used in cases of fuel hydrocarbon, halogenated and non-halogenated organic compounds, and pesticide contaminations (Koul and

Taak, 2018). The result in ex-situ remediation is commonly water and common dioxide, as oxygen is an essential component in this type of remediation model (Defender, 2015).

Soil washing is a technique based on mineral processing, which scrubs soil ex-situ to remove contaminants. This is done in either of two ways. The first is by dissolving the contaminants in a wash solution, done by chemical manipulation of the pH. The second way that soil washing could be done is by concentrating the contaminants into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing. Soil washing is typically done in contaminants of heavy metal, radionuclides, and organic compounds (n.d.).

Electrical Resistance Heating (ERH)

Electrical resistance heating, also known as ERH, is a newer technology used as an in-situ soil remediation technique where the soil is cleaned from contaminants without removing the soil from the site. ERH is the process that we will be modeling throughout this project. ERH uses a system of electrodes, heating rods, and extraction wells to remove the contaminants from the soil. The heating rods are placed in the soil with extraction wells between them. The soil is heated to the boiling point of the chemical contaminant so it will vaporize. Once the chemical is vaporized, the extraction wells vacuum the vapors out and bring them to the surface. Once the vapors are above ground, the contaminants are treated before they are safe to release into the atmosphere (2017). The vapors are treated based on what chemical they are and the local air permit discharge requirements. Among the several different methods to treat the chemicals, we used the method of condensing the vapors if the concentrations are high. Additional methods are based on physical, chemical, and biological processes (n.d.). Physical processes include absorption and condensation. Chemical processes include oxidation, and biological processes include biodegradation. Determining which of these processes to use depends on different factors and is chosen on a case by case basis (n.d.).



Source: Pope and Nienkerk 2002

Figure 6. An image of an implemented ERH system (Pope & Nienkerk, 2002).

It is important for the soil to have moisture in it since soil is an electrical resistor. The electrodes send the electrical current through the moisture in the ground. The temperature of the soil is typically around the boiling point of water, which is 100℃. The electrodes must be made out of an electrically conductive material and are often arranged as “stacked” in order to get maximum efficiency in heating the ground. Power controllers are used to power the electrodes, and isolation transformers are used to ensure electrical current is only between installed electrodes. A wetting system consisting of water or a salt water solution is also necessary so the soil does not dry out near the electrodes which would interrupt the current. ERH can be used on different soil and sediment types. However, some types of soil can be problematic. Sites that have rugged subsurface conditions like landfills or waste disposal pits can make a poor conductive material that makes ERH difficult to perform.

Figure 7. Cascade, a company that does ERH, and their set-up (Cascade, 2017).

ERH has been used on some large sites like the Asheville CTS Superfund Site as described above, but also used on other sites such as Pemaco Superfund Site in Los Angeles (2005). There are some challenges when using ERH. Some dangerous aspects of ERH include the high voltage used to heat the soil and questions about how quickly the soil will heat. The poor conductivity of soil also poses a challenge because it is easy to dry the soil out, so it is crucial to keep the soil wet to ensure conductivity. Finally, a large challenge is the vapor extraction and treatment systems. Since these are volatile compounds, they are very dangerous to humans. Proper safety measures need to be followed in order to safely contain and treat the vapors to limit any possibility of human exposure.

Learning Through Superfund Sites

By encompassing the history of Superfund sites, the science behind them, and the legislation and policies that led to where we are in the present day, this topic is very well rounded. Since the goal of this MQP is to stimulate interest in STEM and to educate about the dangers these sites impose on both humans and their environment, we have developed a comprehensive model that explores Superfund through history, math, science, and humanitarian concepts. As we have seen through the Superfund examples previously, like Love Canal, policymakers and legislators are not always held accountable to properly advocate for environmental issues. Thus, it is important to have a well-educated and scientifically-literate public to advocate for proper chemical disposal for the sake of the environment and fellow residents in these neighborhoods, especially in lower-income areas, as these areas are disproportionately affected by contamination.

We wanted to bring these real-world, contextual engineering challenges into secondary schools and colleges, to motivate students with STEM capacity to learn science in order to help the communities that matter to them.

Impact

"Approximately 21 million people live within a mile of a Superfund site," (Taylor & Bramhall, 2022). Superfund sites can affect everyone, and without any support or regulation, there could be a lot more damage caused to these communities and habitats.

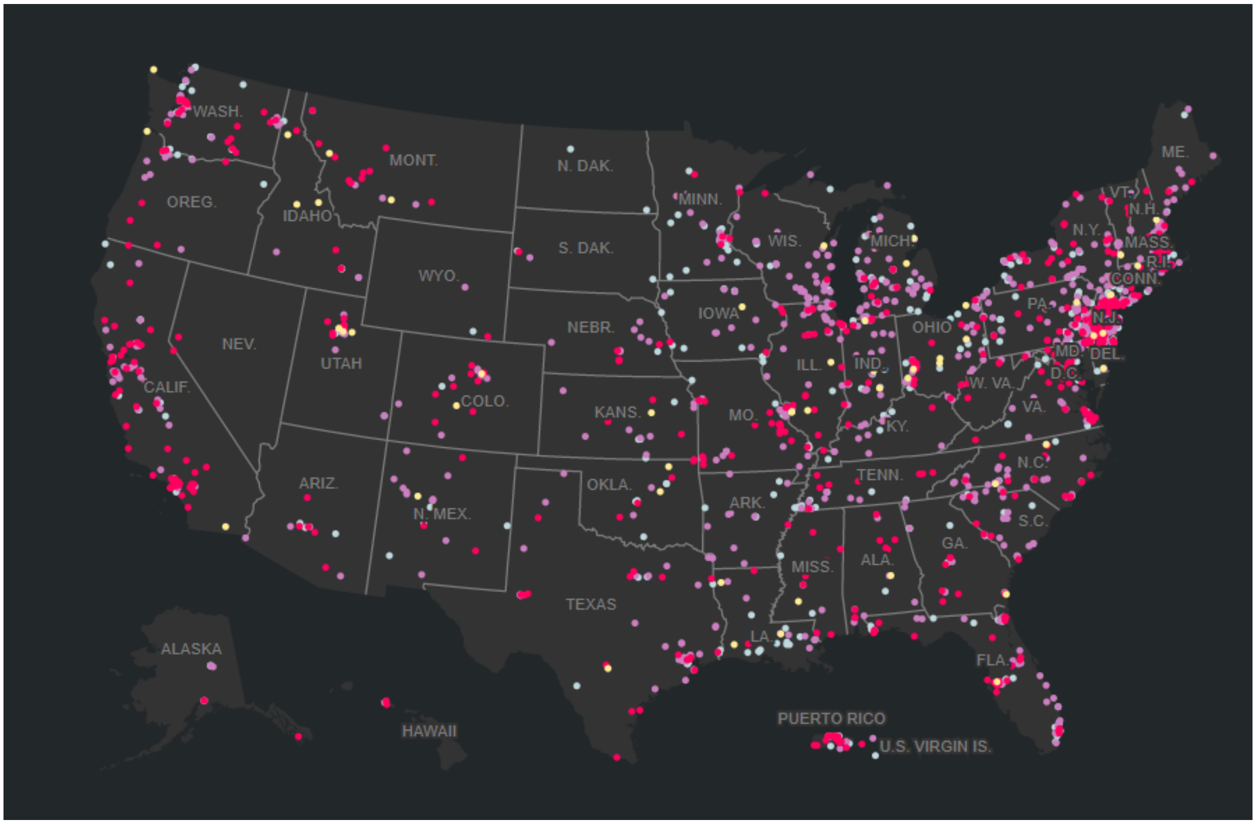


Figure 8. A map of site locations in the United States. Yellow dots are proposed sites, pink dots are active sites, purple dots are sites where construction has been completed, and gray dots are deleted sites (2014).

According to research, living near toxic waste sites can reduce an individuals' lifespan by 1.2 years (Taylor & Bramhall, 2022). Superfund sites are especially prevalent in lower income areas. Of the Superfund sites currently on the National Priorities List, approximately 70% are within a mile of public housing (Bond, 2020). Environmental racism plays a huge role in the unregulated and illicit disposal of toxic waste.

The Superfund program is one of the most influential and important programs implemented by the EPA. The Superfund program remediates contaminated land, responding to environmental disasters and emergencies, and oil spills (EPA, n.d.). It aims to make lasting impacts on communities and habitats, allowing for safe and healthy living for all. Without the EPA, there would not be any regulations on how a company may dispose of their wastes and no programs to remediate these sites.

Soil remediation is the technique used to clean these Superfund sites. There are multiple different methods of soil remediation used. Electrical resistance heating (ERH) is one type of an in-situ soil cleaning method. Electrical resistance heating is a method that uses heating rods to vaporize contaminants in the soil followed by a suction system that removes the vapors and treats them. ERH is a soil remediation technique that can be demonstrated in the form of a kit to show individuals how this chemical engineering process works. A demonstration like this can help engage students in engineering and allow them to learn more about the STEM field.

Making a small-scale model of electrical resistance heating remediation is something that we have not been able to find in other literature or research, since this information is very proprietary. We wanted to model this process on a smaller scale to use as a learning tool. This project is a mix of chemical, environmental, and human engineering. Additionally, this can be used as a learning tool for college students to run tests on, and understand the process and logistics around ERH. This project is aimed to bring awareness to an issue that impacts millions.

Methodology

This MQP aims to demonstrate one method of soil remediation by producing a model kit of a Superfund site using electrical resistance heating. Our main goal of this project is to exemplify the dangers of improperly disposed chemicals, and what can be done to remedy the environment after a disaster. There had been previous work on a model done through the Women's Impact Network (WIN) funded summer research project grant. The main goal of that project was to provide a kit that was cost-effective and could be easily implemented into middle school classrooms to spark interest about STEM in students. Our project deviated from that goal and focused more on a kit that could be presented to kids and used by college students.

One of the main goals of our model kit was to make it so that it would be easy to understand for people with little engineering background. A major problem presented when designing this type of model was finding out how electrical resistance heating worked, since companies do not typically release this proprietary information. We found basic processes on how the system worked, but not detailed information on how to set up a small-scale system. As a team we came up with a design that would theoretically demonstrate ERH. With help from the WPI machinists, we worked together to build our design that would allow us to test our ERH model and show the soil remediation process.

Kit Design

We began our process by brainstorming what kind of kit we would want to design to show how the soil cleaning process is done on a larger scale. Prior work had been done to design an ERH kit; however, the previous kit was designed to implement in classrooms, which was different from our goals (Boudreau, DiBiasio, Dodson, 2019). The previous kit had no suction system, and no condenser system, and water flowing through the system was meant to be tested after passing around the heating rods. We wanted to design a kit for ERH, but we wanted it to be more realistic. We used the heating rods from the old system in ours. Our proposed model is shown below in Figure 9.

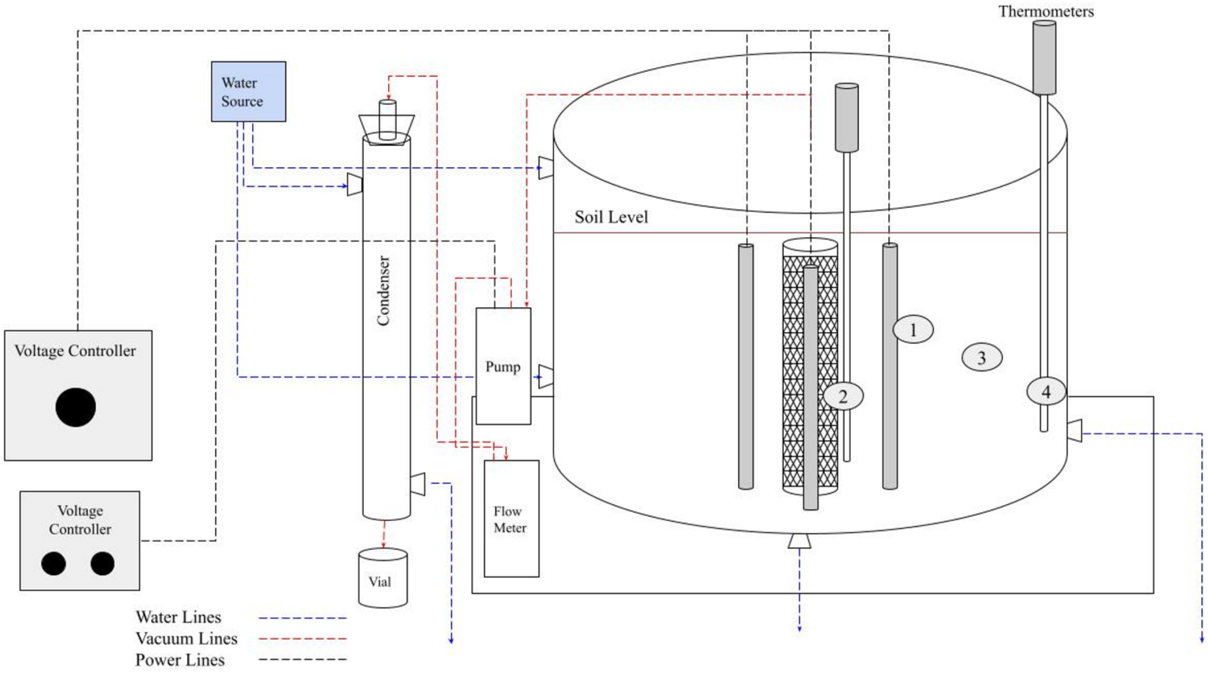


Figure 9. A diagram showing our design for the ERH kit.

A 6-inch acrylic tube with a 10-inch base was used to hold sand and soil in our model. The acrylic tube was constructed with inputs and outputs for a stream of water, and a drain at the base. Acrylic was used because it is clear so observations could be made, and it had a high enough melting point to sustain the temperatures of the system. Rubber tubing was used to connect the water inlet to the system, and the water outlet to a drain. An air pump, vacuum pump 12V Mini Diaphragm Air Compressor, and air flow meter were attached to the base. The air pump was connected to a Laboratory DC Power Supply to control the voltage. The air pump was not to exceed 12V, since that was the maximum design voltage specification. Three heating rods were used to heat the system to the desired temperature. The heating rods were connected to a Powerstat Variable Autotransformer to control the voltage sent to the heating rods. The voltage was not to go above 35V or a power of 8.33A. This allowed us to control the rate at which the soil heated and control the rough temperature of the system. The temperature of the soil stayed around 65℃. Both power supplies were plugged into a GFCI outlet since water was used throughout the system. There was a suction strainer in the center of the system that was connected with rubber tubing to the inlet of the pump. A rubber tube was connected to the output from the vacuum pump air compressor to the flow meter and then inserted into a metal rod in a rubber stopper. The rubber stopper was inserted into the top end of the condenser. The tubing and piping allowed for vapors to be vacuumed out of the system and sent into the condenser. Tubing for cooling water in and out was connected to the condenser from the cooling water supply. The condenser was held up by ring stands and clamps. 40 milliliter dram vials were placed under the open end of the condenser. Below is an image of the final model as Figure 10.

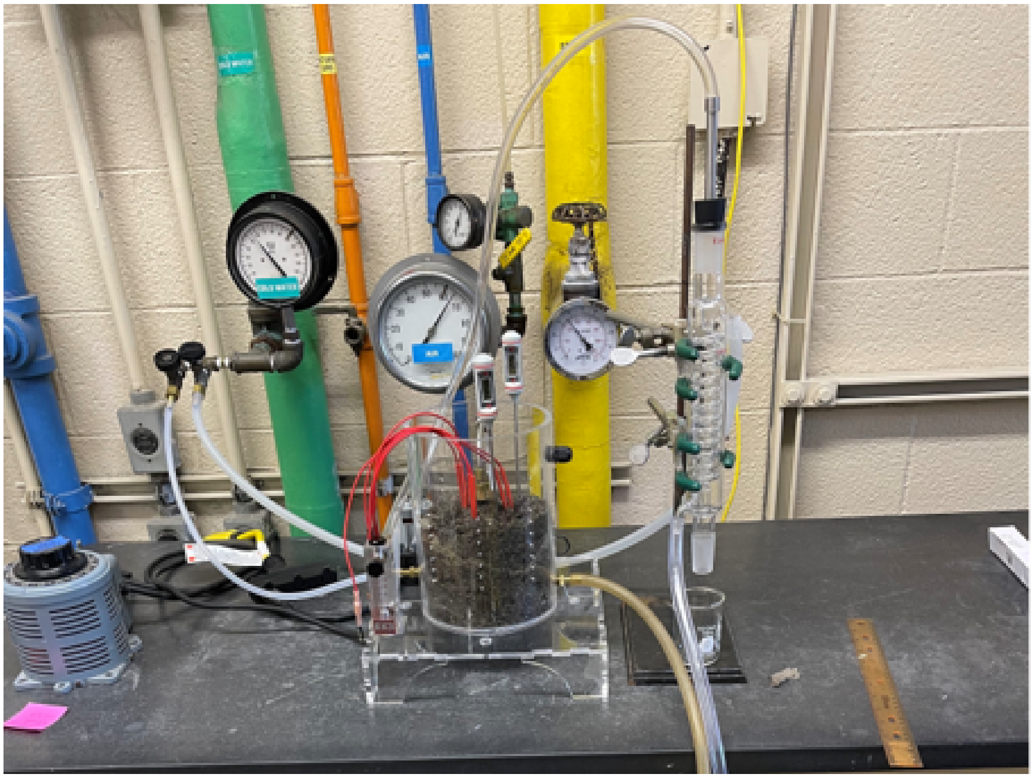


Figure 10. Completed Superfund site remediation modeling kit.

Chemical Choice

There were three main constraints when trying to choose a chemical to use in our Superfund site remediation modeling kit. First, the chemical needed to have a boiling point that was less than 100℃, which is the boiling point of water. The chemical's boiling point had to be lower than the boiling point of water so the chemical vapors would evaporate first, ensuring that the contaminant vapors were collected, rather than water. The second constraint was that the chemical is safe as a gas, since the system was being heated and the vapors were being collected from the system. The vapors could not be harmful, since there would still be the chance of the vapors escaping the air pump and being released into the atmosphere. Finally, the chemical chosen for the kit must be easily detectable to make sure that it was actually removed from the system. After much deliberation and consultation within the chemistry department at WPI, ethanol was chosen as the chemical to contaminate the model system with. Ethanol was chosen as it has a low boiling point of about 78.6°C. Its vapors are relatively safe, but we would use such a small amount even with dilution, so that the vapors released would not be harmful. Ethanol is easily detectable through analysis with gas chromatography, so it passed the detectability test.

When using ethanol, proper safety precautions were observed. Eye glasses and gloves were always used when handling chemicals. Hard hats were worn in the Unit Operations lab. The model set-up was always monitored when the heating rods were on and the system was never left alone, as ethanol is highly flammable.

Temperature Distribution

For the model, we had to determine how the heat from the heating rods would travel all throughout the system to effectively vaporize the ethanol. To do this, a mock acrylic tube was used for the temperature distribution trials, where the heating rods were placed in the soil. A mixture of soil and sand was put in the acrylic tube, and the heating rods were placed equidistant, about 2.5 inches, apart from each other within the sand and soil mixture. The soil was moistened in order to keep the soil and sand from drying out from the heat from the heating rods, while the moisture also acted as a conductor of heat. The greatest temperature distribution was determined to be close to the heating rods, where this area experienced the greatest amount of heat. Soil is not a good conductor of heat, but rather it is the water that helps distribute the heat in the system. For the next trial, the heating rods were moved closer together with a range of 1.5 to 2 inches apart. More water was added to saturate the soil, which helped slightly widen the temperature distribution range and conduct heat throughout the soil system. One thermometer was placed in the center of the heating rods and the other placed on the inside edge of the acrylic tube. The thermometer was also moved throughout the system in order to determine this distribution. Different temperatures, voltages, amps, and observations were recorded. We found 20 volts supplied to the heating rods from the Laboratory DC Power Supply resulted in a thorough temperature distribution in the soil between the heating rods. The areas near the walls of the acrylic never reached a temperature higher than 33℃, which ensured proper safety measures during the experiment, since the acrylic was not threatened to melt from the heat.

Model Set-Up

A mixture of soil and sand was placed in the acrylic tube, about 5 inches high, ensuring that it covered the top of the suction strainer. All tubing was connected throughout the system. The tubing was connected from the suction strainer to the pump, the pump to the flow meter, the flow meter to the condenser, the condenser cooling water inlets and outlets, and the system water inlets and outlets. The heating rods were placed in the soil, equidistant around the strainer, approximately one inch from the strainer, and two inches from each other. Two thermometers were placed in the soil, one near the acrylic edge and one near a heating rod. Several trials were done with varying milliliters of ethanol diluted in 20 milliliters of water, and these mixtures were added to the system. Some of the ethanol-water mixture was added using a pipette and put directly into the soil, while some of it was poured on top of the soil and allowed to seep into the soil. This allowed for a random distribution of the contaminant, which is more similarly modeled to a real Superfund site. The system's water inlet was turned on just until the soil was damp. The cooling water to the condenser was turned on. The power to the heating rods was turned on and set to 20 volts. The power to the pump was turned on and set to eight volts.

System Operation

The system took between 15 to 20 minutes to completely heat up. The thermometers were moved throughout the soil to the four different locations to test and record the temperatures. Water was added to the system if the soil started to dry out. There was rubber tubing to and from the pump to make sure no liquid or soil particles were being sucked through the strainer. If there was the need for it, the pump was turned down to decrease the air flow rate. The rubber tubing and condenser were also closely monitored for any condensation or vapors. At the time the first drop was observed, the time was recorded. Samples were collected in dram vials, which were labeled and switched out every five minutes.

Shut-Down

The power to the heating rods was turned off. The power to the air pump was turned off. The heating rods were removed from the soil and allowed to cool. This also allowed the soil to cool. Both the power supplies were unplugged from their wall outlets. All tubing was disconnected, drained and rinsed. After the soil was cooled, it was removed from the kit and disposed of properly. Everything was rinsed, cleaned out, and allowed to dry.

Gas Chromatography

Gas chromatography was used to analyze the collected samples. Gas chromatography allowed for an analysis of the concentrations of the compositions injected into the machine. Since the sample extracted from the model was a condensed vapor, this was a good way to see if the condensed vapor contained any ethanol. The gas chromatograph used in the experiment uses a flame ionization detector (FID) to vaporize the injected sample, and displays the volatile components on a plot. Graphs were obtained from the gas chromatograph, which included peaks and retention time once the sample was analyzed by the system. From these peaks and retention times, the concentration of ethanol in the system was analyzed through comparison to a standard curve.

Results and Discussion

Throughout the construction and testing of our kit, we were able to collect and compile our results. The ERH modeling kit that we designed was effective at completely removing the contaminant we added to the soil, while also producing other important data as well, such as the temperature distribution of the heating rods within the system. From the kit, we were able to test the collected samples, as well as conduct a cost-analysis of the model to see if it would be feasible to produce these kinds of kits to schools for education purposes.

ERH Kit

The kit we designed was a successful model of using electrical resistance heating to clean a contaminated site. The heating rods heated the soil to the desired temperatures, and provided a thorough temperature distribution throughout the soil. The suction strainer that was used in the model properly removed the vapors from the soil, and fed the vapors into the condenser. The vacuum pump had to be run at eight volts in order to remove the vapors at a high flow rate without removing liquid from the soil. The condenser was successfully used to condense the vapors from the soil, and it provided us with liquid samples to be tested through gas chromatography.

Temperature Distribution

While the kit was running, temperatures were taken in four different locations at five minute intervals. Figure 11 below displays the recorded temperature locations throughout the model during the experiment.

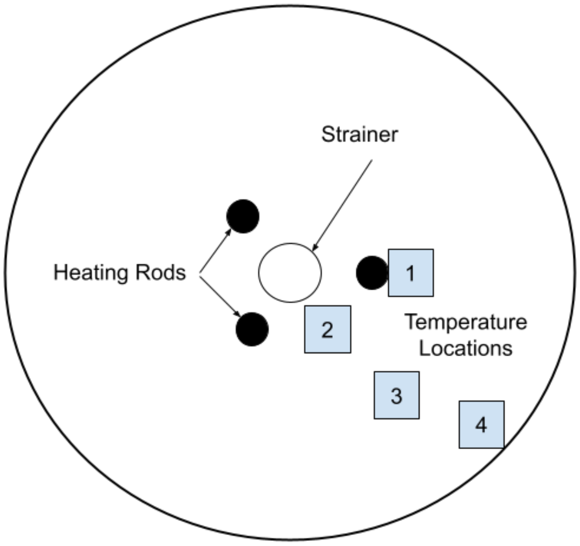


Figure 11. A top view showing the recorded temperature locations.

Temperatures were taken directly next to a heating rod, location one, between two heating rods, location two, between a heating rod and the outside acrylic edge, location three, and on the outside edge right next to the acrylic, location four.

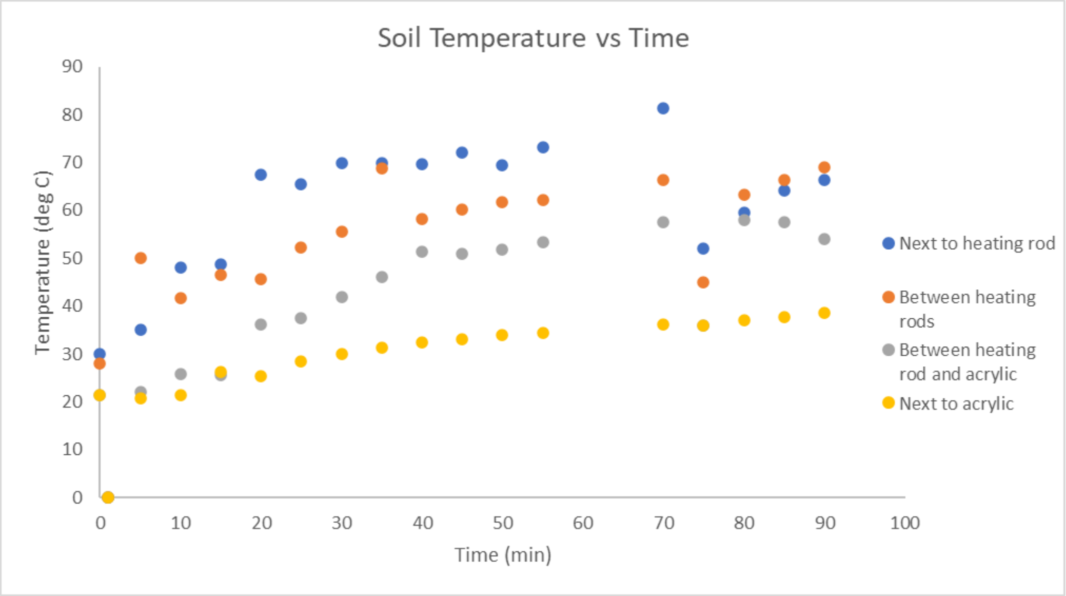


Figure 12. This graph shows the temperatures at the four different locations at five minute intervals throughout the duration of Trial 1.

Figure 12 above shows a few general trends over time. In general, the longer the kit ran, the hotter the heating rods and surrounding soil got. The further away from the heating rods, the cooler the soil temperature was. The temperature recorded at the heating rods and between the heating rods rose at a faster rate compared to locations three and four, which were further away from the heating rods. All of these trends were to be expected. At 75 minutes, there was a drop in temperature across all four locations. This was because the heating rods were moved throughout the system, which allowed some heat to be released from the soil. After the heating rods were placed back in the soil, the temperatures slowly increased again. This graph shows that there was a thorough and consistent temperature distribution throughout the system since after the initial spike, where the temperatures seemed to increase at a similar rate.

Gas Chromatography Results

All samples were run in the gas chromatograph, which produced plots of the sample indicating the area of the peak and the retention time. Standards of known concentrations of ethanol and water were also run to determine the areas and retention times of those samples, which allowed us to create an ethanol standard curve.

The gas chromatograph was able to detect the presence of ethanol in our samples. From the graphs given by the gas chromatograph, we determined if the peak was ethanol and the relative amount of ethanol. Peaks with a retention time of approximately 0.64 min were identified as ethanol, and since the amount of sample injected to the machine was the same throughout, we could tell the larger the area of the peak, that meant it had a higher concentration of ethanol. In general, the first couple samples had peaks with smaller areas, the middle samples had larger areas, and the ending samples showed a decrease in area until no peak was detected. This was a consistent result throughout all three trials.

Ethanol Concentrations

A standard curve of known concentrations were used to determine the concentrations of the unknown sample. A table of the milliliters of ethanol and water and their known concentrations are shown below as Table 1.

Table 1. Amounts of ethanol and water, and the concentrations used to make a standard curve.

Sample #	Ethanol (mL)	Water (mL)	Percent Ethanol
1	1	5	14%
2	3.5	10	22%
3	1	0	100%
4	3.75	2.5	54%
5	2	1	61%
6	1	2	28%
7	3	4	37%
8	0	1	0%
9	3	1	70%

These amounts of ethanol and water were measured and injected into the gas chromatograph. The areas from the graphs and the concentrations from the table were used to create Figure 13 below.

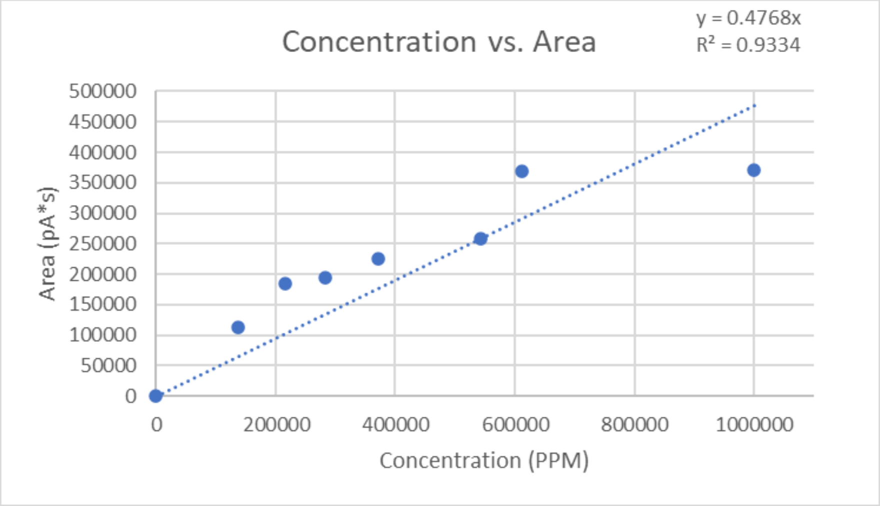


Figure 13. The standard graph for known concentrations of ethanol and water.

Different volumes of ethanol were added to the system for different trials. The volumes of ethanol varied from three to seven milliliters of pure ethanol, diluted with 20 milliliters of water. As the kit ran, the vapors that were pumped from the soil were condensed and collected as samples. Below is a graph, Figure 14, depicting the results from our three trials.

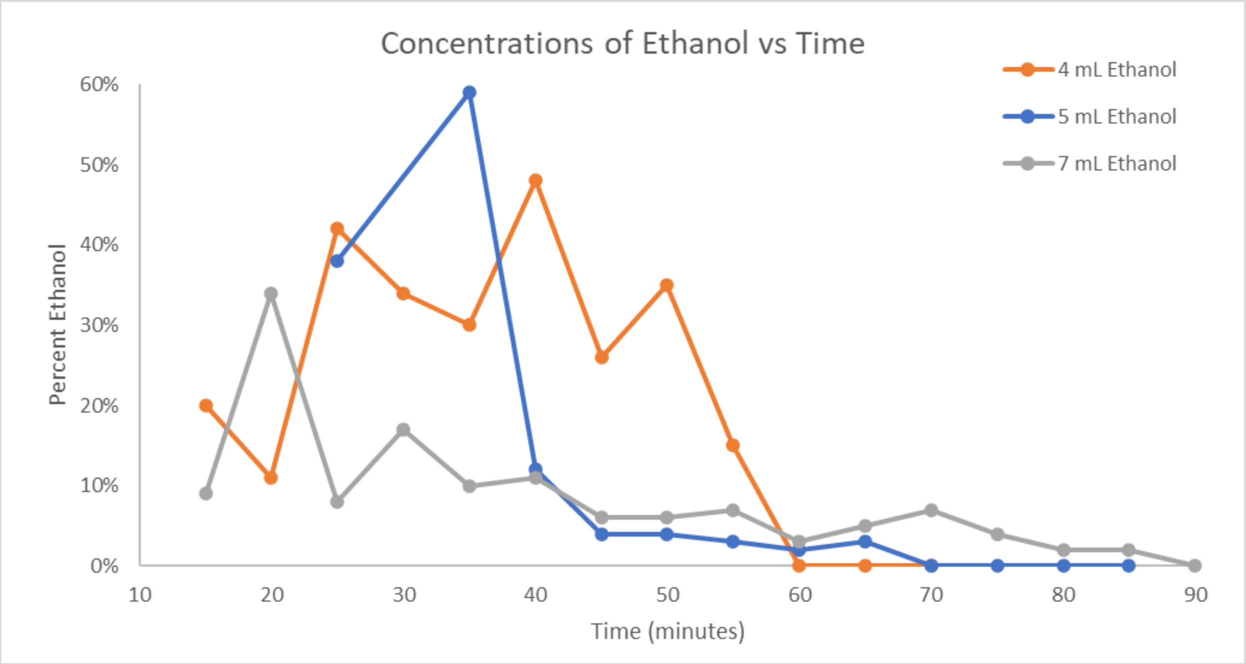


Figure 14. Graph of ethanol concentrations in samples collected from the condensed vapors over time for varying ethanol soil contaminations.

There are some trends that can be seen and analyzed from Figure 14. One general trend is as time increased, the ethanol concentration in the collected samples decreased. There were some peaks of the concentrations in the middle of the remediation process, but overall the concentration started low, increased, and then decreased until it hit zero. Four milliliters took 60 minutes to eliminate the ethanol, five milliliters took 70 minutes to eliminate the ethanol and seven milliliters took 90 minutes to eliminate the ethanol. Comparing the five and seven milliliter trial to the four milliliter trial, an additional milliliter of ethanol took an extra 10 minutes to eliminate the ethanol from the system. The more ethanol put into the system, the longer amount of time electrical resistance heating took to remove it.

By Sample 10 from the five milliliter trial, no more ethanol was detected in the liquid since there were no peaks plotted by the gas chromatograph. Samples 11 and 12 were taken after moving the heating rods to a different position in the soil. Samples 11 and 12 did not show any signs of ethanol, signaling that the ethanol was properly remediated from the system, even after the change in heating rod placement. This means that the heat was properly distributed through the soil, and the pump sucked more than enough vapor in to collect the ethanol from the system. As expected, it took the trial with four milliliters of ethanol to take less time to vaporize and clean the soil of the contaminant than the five milliliter trial. As expected, the seven milliliter trial was also cleaned, but took longer than the previous trials.

Some things can be inferred from the concentrations as well. Since we were not directly testing the soil, we can infer that since no ethanol was being condensed at the end, either immeasurable or no amounts of ethanol remained in the system. However, it can be assumed that some ethanol vapors were being lost to the environment, so the samples collected did not contain 100% of the ethanol put into the system.

Cost Analysis

As materials were collected for the modeling kit, we tracked the costs of all the different components put into constructing the kit. We only accounted for the materials we had to purchase. Some materials we already had or borrowed, so we did not account for those costs in our analysis. The total cost of the materials used throughout the site simulation amounted to about \$210, and then an additional \$640 for labor. Due to the price of this kit, it would be more feasible to be used as a demonstration tool as opposed to trying to implement this kit in classrooms. Now that there is a detailed design, these kits could be produced for about \$115. A detailed list of materials and each respective cost can be found in Appendix A.

Conclusion and Recommendations

Throughout the project, we were able cite several places to make recommendations for the following trials done with the model. One of the first suggestions we have would be when designing the model, to have two inlet water valves on both sides of the acrylic tube. We found that only having two on the left side was insufficient in saturating the right side of our model, while the two valves we had ended up oversaturating the soil on the left side of the model. By having more than the two inlets, it would ensure that the right side of the soil is equally as saturated.

Additionally, tighter fittings would be suggested as the tube fitting from the flow meter reading to the condenser was loose. This fitting allowed liquid to escape meaning a loss of ethanol and water, which could have changed the concentrations. The temperature of the existing heating rods should also be tested. Different heating rods seemed to give different temperature readings during the testing, which could have affected the results. A consistent heating tool throughout the system would be beneficial to compare results.

Further testing could also be done. Some things that could be altered and tested are the size of the heating rods, the size of the suction strainer, the size of the system with the existing heating rods, and the grain of the strainer. Testing could also be done with different chemicals to see how those work with ERH. Different methods of introducing the contaminant in the system could also be tested. The contaminant could be mixed with the water that saturated the soil to maybe produce a more evenly dispersed contaminant. The saturation of the soil is another interesting aspect to measure. The more saturated the soil the longer it took for the system to heat, and the harder it was for the suction strainer to remove vapors. The less damp, the easier it was. It would be interesting to see if there is a measurable amount of water that can be added to give the best results with the collection process.

Another suggestion that we could make would be to have additional testing of the samples. The gas chromatograph machine used sometimes gave varied results for one sample. These inconsistencies could have been settled using a different gas chromatograph machine. However, our results were often in an expected range, so they were considered to be true with a small margin of error.

Through research, design, and testing of this kit we learned about the implications of Superfund sites. This kit would be a great education tool. In secondary schools, this could be used as a demonstration tool in classrooms. Teachers, or an experienced user, could run the system, showing the students how the kit works. The students could be assigned a research project on a Superfund location, history of Superfund sites, or research on the chemicals commonly found in Superfund sites. This demonstration and research assignments in secondary education could spark an interest in STEM while enveloping other subjects into the demonstration. In higher education, specifically the chemical engineering curriculum this could be implemented as a Unit Operations Lab. This kit will help chemical engineering students practice with subjects such as heat transfer, thermodynamics, and explore real world applications of chemical engineering.

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Appendices

Appendix A: Material and Price List

Material	**Cost**
Acrylic base (10 inches long by 10 inches wide)	-
Acrylic tube (6 in tall, 6 in outside width, 1/4 in thick)	-
Aluminum heating rods (3)	$60
Cooling water - utility cost	-
Dram vials (72)	$60.48
Ethanol (60 mL)	$0.18
Flow meter (in SCFH)	-
Glass graduated cylinder (25 mL)	-
Graham condenser (20 mm, 24/40 dim)	$19.97
Laboratory DC Power Supply	-
Metal pipe (1 3/4 in long, 1/2 in in diameter)	-
Pasteur pipette (9 in, 200)	$14.30
Pipette bulbs (2)	$7
Plastic ball valve (3-way, PVC, 1/4 in)	-
Plastic tubing	-
Powerstat Variable Autotransformer	-
Ring stand with clamps	-
Rubber stopper	$0.81
Ruler	-
Sand (1 bag)	-
Simpson Amp Clamp	-
Soil (1 bag)	$3
Suction strainer	$19.51
Thermometers (2)	-
Vacuum Air Pump Compressor (12V)	$25.49
Labor	$640
Total	$850.74

Appendix B: Raw Data Tables

Table 2. Trial 1 Starting Statistics

Water/Ethanol (mL)	20/5
Distance between Heating Rods (in.)	1-1/2
Height of Soil after water (in)	4-5/8
Volts for Heating Rods (V)	20
Volts for Pump (V)	7.5
Air Flow Rate (SCFH)	18

Table 3. Trial 2 Starting Statistics

Water/Ethanol (mL)	20/4
Distance between Heating Rods (in.)	2
Height of Soil after water (in)	4-3/4
Volts for Heating Rods (V)	20
Volts for Pump (V)	8
Air Flow Rate (SCFH)	14

Table 4. Trial 3 Starting Statistics

Water/Ethanol (mL)	20/7
Distance between Heating Rods (in.)	2
Height of Soil after water (in)	5
Volts for Heating Rods (V)	20
Volts for Pump (V)	8
Air Flow Rate (SCFH)	15

Table 5. Trial 1- 5mL Ethanol: Temperatures

Time (min)	Location 1 (℃)	Location 2 (℃)	Location 3 (℃)	Location 4 (℃)
0	30	28	21.5	21.4
5	35.2	30	22	20.7
10	48	41.7	25.8	21.5
15	48.8	46.5	25.6	26.2
20	67.5	45.6	36.1	25.3
25	65.5	52.3	37.6	28.4
30	69.8	55.5	42	30.1
35	69.8	68.7	46.2	31.4
40	69.6	58.2	51.4	32.4
45	72	60.3	50.9	33.2
50	69.5	61.7	51.9	33.9
55	73.2	62.2	53.3	34.5
70	81.3	66.4	57.5	36.2
75	52	44.9	36	36
80	59.5	63.2	58	37
85	64.2	66.3	57.5	37.8
90	66.4	69	54.1	38.7

Table 6. Trial 2 - 4mL Ethanol: Temperatures

Time (min)	Location 1 (℃)	Location 2 (℃)	Location 3 (℃)	Location 4 (℃)
0	24	21.8	22.1	21
10	49.5	32	27	22.3
20	62.3	36.2	34.5	25.9
30	85.6	53.1	49.3	29.5

40	88.5	63.2	49.6	35.1
50	125	50.2	50.9	38.5
60	137.8	53	52	40

Table 7. Trial 3 - 7mL Ethanol: Temperatures

Time (min)	Location 1 (℃)	Location 2 (℃)	Location 3 (℃)	Location 4 (℃)
0	31.5	21	20.4	21
15	81.1	44	44	23.5
20	84.3	56.8	46	25.9
30	80.1	63.8	51.2	36
40	81.8	61.5	58.6	33.3
50	76.5	60.2	61	35.7
60	80.9	60.2	61	35.7