Rocket Stove:

Heat, Light, and Power

Disaster Relief Solutions

Senior Design Final Report 2017

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Certification

I certify that the ideas, design and experimental work, results, analysis, and conclusions set out in this report are entirely our own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other courses or institution, except where specifically stated.

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Summary

The 2016-2017 academic year marked the second year of the Disaster Relief Solutions senior design team at LeTourneau University. As a team, Disaster Relief seeks to use God-given intellect and engineering problem solving skills to meet basic needs of people in developing countries and disaster situations. Using Maslow's hierarchy of needs, the team identified the fundamental needs common to both contexts, which, after physical security, are heat, food, and clean water. This year's team expanded and built upon the previous work of Disaster Relief in exploring rocket stove technology as a practical, simple tool that can aid with all of these needs. A heuristic approach allowed the team to investigate multiple aspects of the rocket stove with an aim to optimize the stove for efficiency, heat output, low emissions, and field expediency. An optimized rocket stove burns less fuel than three stone fires, uses virtually any available biomass for fuel, and can be built from a variety of common materials. With such a stove, an individual in a disaster situation will have ample heat for body warmth, a cooking fire, and a method of boiling water for sanitation. The added benefit of electrical generation from a rocket stove, an area of study and testing this year, will provide enough power to charge a cell phone and allows the user to call for help in an emergency.

The team investigated the optimal dimensions of the rocket stove, the effects of secondary burn (air injection into the smoke stream) on heat output and pollutant production, alternative materials and construction methods, and conversion of heat to electricity. Findings from these studies will allow organizations or individuals in disasters or other countries to construct effective stoves. To disseminate the team's results, multiple publications were written to summarize specific stove concepts and provide step-by-step construction guides. The publications and a summary of the team’s findings were compiled into a website to make the information available to organizations in individuals around the world.

FIGURE 1: 2016-2017 DRS SENIOR DESIGN TEAM

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1 Project Overview

1.1 Introduction

Disaster Relief Solutions is working to bring relief and higher quality of life to people in disaster situations and developing countries by using God-given intellect to optimize a biomass-fueled rocket stove. The rocket stove is aptly suited to meet the cooking and heating needs of these groups as it burns cleanly and efficiently and can be manufactured from in-situ materials. Electrical power generation is an additional need that can be met with add-on components to the rocket stove. When communications and fuel efficient heat sources are jeopardized, the optimized rocket stove that Disaster Relief Solutions is working toward can provide a safe, clean, efficient alternative to traditional fires or fossil-fueled stoves.

This year's team is building on the progress from last year to test and optimize stove performance through investigating stove internal geometry, fire efficiency, secondary burn, pot support accessories, and a thermoelectric generator tool. Previous testing results showed that building a stove to have specific dimensional ratios between the air inlet, air outlet, and chimney height gave significant improvements on fire temperature and performance. Using these discoveries, the team is seeking to discover which stove dimension ratios exhibit the highest efficiency. Further, the team is testing the effect on fire performance and smoke pollutant output of injecting varying amounts of air into the chimney at different heights. The thermoelectric generator is a useful concept that the team is applying to the rocket stove to capture thermal energy and convert it to usable electric energy.

Design of Experiments (DOE) is the team's primary tool in testing, as it facilitates comparison of multiple stove configurations and is an industry standard heuristic testing method. The data, stove parameters, principles, and design concepts found by the team during this project will be disseminated by means of a website and technical publications. The team is intending for these publications to equip people in disaster situations or developing countries to construct their own, high-performing rocket stoves.

1.2 Project Goal

The aim of this project is to optimize rocket stove performance by considering efficiency, pollutant output, and heat output, develop field expedient stove concepts, design an easily implementable thermoelectric generation tool for rocket stove use, and publish the team's findings in technical guides useful for multiple literacy levels. The team will optimize stove performance by finding ideal stove inlet area to outlet area ratios for both heat output and efficiency. Additionally, the project will determine ideal quantity and location of secondary air injection to obtain gasification of smoke and a more efficient fire. Information will be made available to the public via a website and multiple technical guides.

1.3 Project Mission Statement

Using God-given intellect fueled by compassion, Disaster Relief Solutions is heuristically designing a low-fuel, clean-burning stove to cook food and charge electronic devices in emergencies and developing countries.

1.4 Project Objectives

- Establish the most efficient and best performing stove inlet area to outlet area ratios.
- Determine the most effective quantity of air and location of air input into stove chimney for maximum gasification.
- Determine the optimal stove configuration for minimal carbon monoxide output.
- Supply a continuous charge via USB to a cell phone using thermal power collected from the stove by the thermoelectric generator.
- Design and prototype a thermoelectric generator tool that can be used with any rocket stove to supply continuous USB power.
- Update the team's website to document the team's findings and disseminate technical information on rocket stove construction.
- Create and publish technical guides that instructs readers with moderate literacy how to build an in-ground rocket stove and a traditional, free standing rocket stove.
- Create and publish pictorial guides that instructs readers with limited literacy how to build three different types of basic rocket stoves.

1.5 Deliverables

- Stove working prototypes
- Thermoelectric generation tool working prototype
- Midterm presentation
- Final stove with optimized geometry and features
- Electrical thermoelectric generation tool
- Field technical guides for in-ground stove and free-standing stove construction
- Pictorial construction guide for in-ground rocket stove, In-Ground Stove Support System, and basic traditional rocket stove
- Website with findings and publications
- Final report
- Final presentation

1.6 Chronological Overview

The 2016-2017 Disaster Relief Solutions senior design team used design process thinking and an iterative approach to reaching its goals. Beginning with a literature review allowed the team to formulate a solid foundation of theories and principles dealing with rocket stoves, thermoelectric generators, and the needs of developing countries. This review included the final report and the final senior design presentation from the 2015-2016 Disaster Relief Solutions team. Online sources were also researched, compiled by each team member, and presented to the team. (Section 2.3) As this literature review progressed, the team divided into groups of two and three to build test stoves and gain hands-on experience with rocket stove principles. This build day helped the team to understand and experience first-hand the advantages and uses of rocket stoves and to suggest goals and stove configurations to use in the coming year. The results of this activity were discussed in team meetings and led to a second build day, where the same smaller groups of team members improved previous stoves and tried out new ideas. (Figure 2) These build days gave the team a jump start in brainstorming activities, where members shared suggestions for topics to explore over the course of the project. These ideas were narrowed down into three main headings: Stove Tests, Electrical Generation, and Field Expediency.

FIGURE 2: BUILD DAY PROTOTYPE STOVE

To devote time and manpower to each of these areas, the DRS team split into three subteams and assigned subteam leaders for each. The subteams used the list of ideas for investigations to formulate a refined list of goals for their portion of the project. Specific plans for implementation of these goals were drawn up, presented to the team, and then put into action. The Field Expediency subteam began a series of “voice of the customer” interviews with a goal of understanding the needs and resources of developing countries. (Section 2.4) Stove team completed planning for three different testing processes to investigate internal geometry, efficiency, and gasification. The first test included a series of six concrete rocket stoves built with different air inlet area and outlet area ratios. To allow for curing, the stove team constructed these six stoves and allowed them to dry for approximately 40 days. (The concrete rocket stoves were constructed to the ratio specifications outlined above and can be seen in Figure 8. They underwent one major revision to extend the chimney height of each stove to match optimal dimensions, which can also be seen in the figure. These test stoves provided a reliable platform for the internal geometry Design of Experiments.) The electrical team started by testing the thermoelectric generators (TEG) that the previous DRS team had used, but found that several had been damaged by heat. They worked to procure and test different types of thermoelectric generators and brainstorm methods of attaching the TEG to the rocket stove. As the fall semester neared its close, the entire team worked together to compile all research, progress, and conclusions into the midterm presentation.

Stove testing began in earnest at the open of the spring semester with the completion of the concrete rocket stove DOE. Once all the tests were complete, the data was statistically analyzed in Minitab with an Analysis of Variance (ANOVA) process and presented to the team. These results were similar to the stove air inlet to outlet ratios discovered by the previous DRS team but were more reliable due to the revised test methods. The Field Expediency team assisted the stove team in DOE testing and then branched out to test their own in-ground rocket stove concept. After multiple design changes and testing trials, this stove proved to exhibit the benefits of a clean-burning rocket stove. Field Expediency then shifted to information dissemination, designing, and writing five rocket stove construction guides. Continuing testing work with TEG's, the electrical team discovered and procured an IPowerTower™[1] for experimental implementation with the rocket stove. This device was designed to charge a cell phone using only the heat from a Sterno™ can, and initial correspondence with the manufacturer gave encouragement that it could help the electrical team investigate rocket stove charging feasibility.

The stove team continued work on the planned DOEs, rebuilding the test stove from the 2015-16 DRS team with stainless steel to better withstand cyclical heating. Upon completion of the stove, the team completed the gasification DOE. This test process investigated the effects of secondary air injection into the rocket stove on fire efficiency and overall performance. At its conclusion, the data was again analyzed in Minitab. The team discovered that air injected into the stove closer to the top of the chimney improved performance more than air injected close to the wood. These conclusions launched the team into the final DOE, which sought to investigate the carbon monoxide output of various configurations of the rocket stove and compare it to that of a three-stone fire. This test found that a rocket stove with an open air inlet and gasification exhibited a maximum carbon monoxide output one-half the level of that of a traditional three-stone cooking fire. The electrical team worked steadily to overcome the risk of overheating the TEG’s in the electrical generation station, and found that a hot air duct controlled by a bimetallic coil could be a practical solution. This device used the angular displacement of the bimetal coil to regulate the amount of heat transferred from the fire to the TEG. The team completed extensive preliminary testing with the IPowerTower™ and air duct device and then proceeded to integrate it with the rocket stove. This design allowed for use with any rocket stove format and prevented overheating of the TEG’s. Though instrumental in helping with stove DOE testing, the Field Expediency team also fabricated a concept of a modular in-ground stove. It used the optimal design parameters discovered by the stove team and can be quickly buried in the ground. (Section 5.9)

To wrap up the progress of the project, all members of the team worked continuously to document findings and procedures. The technical guides written by Field Expediency compiled

[1] “IPowerTower™ Trangia Tablet Battery Charging.” TECTEG MFR. Available: http://tecteg.com/IPowerTower™/ Accessed: February 2017Johnson, C. “Burning Wood for Heating – The Physics.” Available: http://mb-soft.com/public3/woodburn.html. September 2016.

these findings into practical, step-by-step stove construction manuals. The team's website was also updated to reflect the latest investigations and discoveries. All technical guides and presentations were made available through this website to give access to interested parties.

2 Project Background

2.1 Introduction

Around the world, there are many people in developing countries that have too little money to be able to afford fossil fuels for cooking, much less to be able to buy a stove. Thus, most of their cooking is done over a wood or charcoal fire, often inside of the home. Not only are these fires inefficient in burning fuel, they also produce a significant amount of smoke that contains harmful particulates and carbon monoxide gas. These are the main problems that the team has focused on improving by building an expedient and efficient rocket stove.

Though rocket stoves have been around for a long time, very little controlled experimental testing has been done on these stoves. The team could find very little documentation of experimental testing on the optimal internal geometry and ratios between the inlet area, outlet area, and chimney height for optimizing the heat production of a rocket stove. Most stove users discovered during research obtain high performance stoves with only limited fundamental understanding of the stove's operation principles. The best design for a rocket stove, however, can only be determined through a controlled engineering experiment.

Rocket stoves have previously been paired with methods of converting thermal energy to electrical power, as can be seen in BioLite products. However, designs like BioLite's Camp Stove are prone to overheating which can ruin the electronics used in energy generation. Current solutions that exist to address this problem implement a warning light to let the user know the components are getting too hot and the user should dampen the fire. The team could not find any current designs available that address this overheating problem without sacrificing either the component or the fire temperature and efficiency. The team therefore intends to create an expedient form of electrical generation that is inherently temperature-regulated.

2.2 Review of Previous Senior Design Projects

2.2.1 2015-16 DRS Team

DRS is in its second year as a senior design project under the faculty sponsorship of Dr. Scott Anson. This year's rocket stove project has been a continuation of the conclusions made by last year's team. A significant portion of last year's work was devoted to understanding rocket stove physics and fundamentals of obtaining a clean, hot burn. As part of the experimentation, the team conducted two Design of Experiments (DOE) to determine the optimal air inlet to outlet ratio of the stove dimensions. However, this experiment did not include changes to the internal geometry of the stove, but used restricting plates to change the diameter of the inlet and outlet for testing. The previous team identified this as a probable source of error and a topic for future work. This is one of the key components of last year's results that this year's team sought to verify.

The previous electrical team's primary goal was to use a thermoelectric generator to capture heat from the stove and allow the user to charge a phone from USB. The team successfully charged a cell phone, producing 2.5 watts of power with a TEG mounted to an aluminum plate placed in the flames. The team tested a water reservoir, convection cooling, and active water cooling as methods for keeping a low temperature on the cold side of the TEG. One of the TEG's overheated at the conclusion of the verification tests and prompted the previous team to emphasize the need for future work into more effective cooling systems. The electrical team this year set goals of achieving higher wattage with charging, implementing a reliable cooling method for the cold side of the TEG's, and autonomously and mechanically regulating the amount of heat delivered to the TEG's.

Last year's team also built a website to allow dissemination of information. This year's field expediency team in part was created to further the goal of dissemination of information through updating the existing website with this year's progress and compiling pamphlets for distribution to the public. Additionally, the team focused on creating additional field-expedient stove designs whose materials would be even more accessible to users in developing countries.

2.3 Literature Review

The team found several examples of low-emission stoves in production that protect health and reduce global warming potential. Aprovecho Research Center, a non-profit organization focused on improving sustainable living, has achieved a 90% reduction in carbon monoxide (CO) compared to an open fire in their lab tests. Other findings indicate that rocket stoves have the potential to cut fuel use to 50% and reduce CO emission by 90%.[2,3] By increasing combustion efficiency, one can obtain this decrease in fuel use of rocket stoves.

Rocket stoves follow a set of similar characteristics that can be used to identify them from a typical charcoal grill. For example, some significant features of rocket stoves include:[4]

- J-shaped chimney design
- Insulated combustion chamber
- Insulated chimney
- Wood burns at its base
- Venturi effect takes place
- Operates efficiently
- Inexpensive to construct
- Chimney is included inside the stove

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[2] Winiarski, Larry, Dr. "The Institutional Rocket Stove." Cooking with Less Fuel: Breathing Less Smoke. Aprovecho. Available: http://stoves.bioenergylists.org/stovesdoc/apro/Institutional_Rocket.pdf. Accessed Sept 2016.

[3] Evans, Ianto, PE. "Rocket Mass Heater." 2007. PDF. Available: https://blackfionproduction.files.wordpress.com/2016/07/leslie-jackson-rocket-mass-heaters.pdf Accessed Sept 2016.

[4] Brayden, Mark, et al. "Patterns for Combustion Chambers." *Designing Improved Wood Burning Heating Stoves*, pp. 10–13. Available: bioenergylists.org/stovesdoc/apro/Heat/Heating%20Stoves%20LO-RES.pdf. Accessed Oct 2016.

- Pot skirt

When constructing a rocket stove, there are several dimensions that are important to its function. These dimensions include:[5]

- Inlet Area
- Outlet Area
- Chimney Height
- Ash Pit Height
- Insulation Thickness
- Inlet Length

Considering the important factors above in stove construction, chamber geometry plays a major role in determining performance. For example, the heat transfer to the pot largely determines the fuel efficiency of a cooking stove. If the internal inlet and outlet chambers vary from low pressure, high velocity (smaller diameter pipe) to a higher pressure, lower velocity (larger diameter pipe) then a Venturi effect will occur. This leads to the fire burning at a higher temperature and rate.[6] Additionally, if smoke is compressed, superheated, and oxygenated, it burns and produces secondary combustion, or *gasification*. As a result, injecting air into the top of a chimney can induce gasification (combustion of smoke and vapor) and produce less smoke. Blocking the primary airflow stream will lead to reduced airflow, increased smoke, and increased particulate matter, which translates to wasted fuel. However, this also leads to a very slow combustion process within the stove that can be beneficial when a lower heat is desired for cooking.[7]

Smoke contains combustible energy; leaving it unburned produces waste products that irritate the lungs and eyes. Combustion can be broken up into two categories: primary and secondary. Primary combustion is the burning of solid material directly. Secondary combustion is the burning of those fuels in the smoke and is achieved by superheating, compressing, and adding oxygen to the gas.[8]

Complete combustion of wood should only produce CO_2 and water. Incomplete combustion produces significant levels of carbon monoxide and hydrocarbons. Turbulence in the air flow through the stove is an important factor that can cause any combustible gases to react with the available oxygen for complete combustion.

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[5] Evans, Ianto, PE. "Rocket Mass Heater." 2007. PDF. Available: https://blackfionproduction.files.wordpress.com/2016/07/leslie-jackson-rocket-mass-heaters.pdf. Accessed Sept 2016.
[6] Winiarski, Larry, Dr. "The Institutional Rocket Stove." Cooking with Less Fuel: Breathing Less Smoke. Aprovecho. Available: http://stoves.bioenergylists.org/stovesdoc/apro/Institutional_Rocket.pdf. Accessed Sept 2016.
[7] "Wood Combustion - FlameWorks - High Efficiency Hearth." Wood Burning Combustion. Flameworks, LLC, 2006. Available: http://heartheat.com/flameworksOLD/index_WoodComb.htm. Accessed January 2017
[8] Aysen, Zaid. "Wood Stove Secondary Combustion." Brighthub Engineering. 07 Sept. 2010. Available: http://www.brighthubengineering.com/machine-design/86002-secondary-combustion-systems-for-wood-stoves/. Accessed January 2017.

Conditions for good wood combustion occur in a temperature range of 1100-1500°F. The air-to-fuel ratio needs to be within 10-12 pounds of air per pound of fuel. The combustion chamber needs to be insulated; therefore, there should be no flame contact with cold surfaces. Aprovecho Research Center recommends an insulation thickness of double the fire chamber diameter. [9] Lastly, there needs to be excess air to approach complete combustion[10]. However, if a method for injecting oxygen into the chimney of the fire is implemented, this excess oxygen does not necessarily need to be added at the inlet.

Peer reviewed literature considering rocket stove testing includes the publications of the Aprovecho Research Center and Berkeley Air Monitoring Group. However, this literature provides little comprehensive access to stove testing results. The 2015-2016 Disaster Relief Solutions senior design final report is a crucial resource with specific testing procedures, clear descriptions of findings, and a plethora of unanswered questions that only testing can answer.

Important items to include in documentation during testing are data source, stove type/name, stove classification, fuel type, testing organization (e.g. LeTourneau University, Aprovecho), location (e.g. lab, field, etc.), test type, and test conditions (e.g. weather, new/old stove, season, temp.). Metrics typically used for testing include fuel use, time, energy/fuel efficiency, stove usage, and durability. Considering time variables, metrics include the time per test phase and time per task. Considering stove usage and durability, there are currently no common metrics whereby stove durability can be tested.[11]

The electrical subteam spent the first few weeks of the project familiarizing themselves with the devices that they would be working with throughout the project. This included reading through the datasheets for various TEG's to become more familiar with the temperature limits provided by the device manufacturers and reviewing the previous year's final report to better understand the progress made up to this point. This was the first portion of the subteam's research and it allowed the team to design for preliminary testing.

The subteam also researched the current commercial uses for TEG’s to gain insight on how they were already being implemented. The subteam discovered that TEG devices do not have a very strong presence in the commercial field. The primary use for them is in power generation in space.[12] They are used in satellites that are sent into deep space where solar panels are not an option and extreme cold temperatures in the vacuum of space allow for high efficiency power conversion.

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[9] Winiarski, Larry, Dr. "The Institutional Rocket Stove." Cooking with Less Fuel: Breathing Less Smoke. Aprovecho. Available: http://stoves.bioenergylists.org/stovesdoc/apro/Institutional_Rocket.pdf. Accessed Sept 2016.

[10] Johnson, C. “Burning Wood for Heating – The Physics.” Available: http://mb-soft.com/public3/woodburn.html. Accessed Sept 2016.

[11] “Stove Performance Inventory Report.” *Berkeley Air*, Berkeley Air Monitoring Group, 2012. Available: berkeleyair.com/stove-performance-inventory-report/. Accessed Mar. 2017.

[12] "Thermoelectric Energy Generation Takes Flight for Aircraft and Spacecraft Monitoring." *Thermoelectric Energy Generation Takes Flight | DigiKey*. Digi-Key, 23 Apr. 2014. Available: https://www.digikey.com/en/articles/techzone/2014/apr/thermoelectric-energy-generation-takes-flight-for-aircraft-and-spacecraft-monitoring. Accessed Mar. 2017.

Other research led to the team finding that most lower cost TEG's on the market have very low hot side temperature ratings. This led the team to research higher temperature TEG's. When researching these higher temperature TEG's, the team found a company in Canada, TECTEG Mfr., that makes their own TEG's. The company also makes various units that use the TEG's. Now, with having a company that makes their own TEG's and systems that use the TEG's, the team decided to use an existing system made by the company.

The Field Expediency subteam found that in-ground stoves could exhibit rocket stove attributes and originate from the Dakota Fire Hole/Pit concept. The Dakota Indians are credited with creating this fire technique.[13] However, the fire pit is an ancient technique that goes back as far as man's discovery of fire.[14] African nomadic tribes used pit fires as means of providing warmth without attracting unwanted attention to their whereabouts. In more recent times, the Dakota Fire Pit has been used by the military as a survival technique.

A Dakota Fire hole requires digging two holes.[15] The first hole is usually anywhere between 6 to 14 inches in diameter and can go 12 inches into the ground. This hole serves as the fire chamber and whatever food is cooked will be placed above it. The second hole serves as the airway tunnel and is usually anywhere between 6 to 8 inches and up to 12 inches into the ground. The hole is dug at an angle to intersect with the base of the fire chamber. As the fire burns, hot air moves up the fire chamber. The Dakota Fire Hole takes advantage of the Venturi effect because the upward movement of the air creates an intake in which cool air is drawn from the airway tunnel into the base of the fire. With this continued stream of air intake, the fire burns hotter and more efficiently while producing minimal smoke. The tunnel-like conception of the hole allows the heat generated by the fire to move in a straight upward direction and cook whatever is on top of it.

Compared to a traditional three-stone fire, the Dakota Fire hole burns hotter, uses less fuel for a better efficiency, creates less smoke, is manageable in windy conditions because it is in the ground, provides stealth, requires few tools for building, and can very easily be disposed of after use. Its main disadvantages include soil wetness dampening the fire, the energy input in building the holes, and difficulty getting the fire started.

2.4 Voice of customer

To broaden knowledge on real-world experiences to better serve the needs of people in developing countries, this year's team envisaged obtaining the "voice of the customer". Interviews were conducted for over 10 nationalities from 3 continents. From the responses, shown in Figure 3, kerosene and charcoal stoves were found to be the more prevalent, while wood based fires were used by extremely poor families. A wood-based fire is an assortment of wood sticks placed between three or more stones of similar height. Meals on kerosene stoves

[13] Harvery, Rob. "The Dakota Fire Pit." BoomerPreps. 15 Sept. 2014. Available: http://www.boomerpreps.com/utilities/fire/dakota-fire-pit/. Accessed Feb. 2017

[14] "The History of Fire Pits." Family Fire Pit Reviews. 13 April 2011. Available: http://www.familyfirepit.com/blog/fire-pits-history/#axzz4cjwRGIaU. Accessed Feb. 2017.

[15] Fontaine, Ron. "The Dakota Fire Hole." SurvivalTopics.com. 10 June 2005. Available: http://survivaltopics.com/the-dakota-fire-hole/. Accessed Feb. 2017.

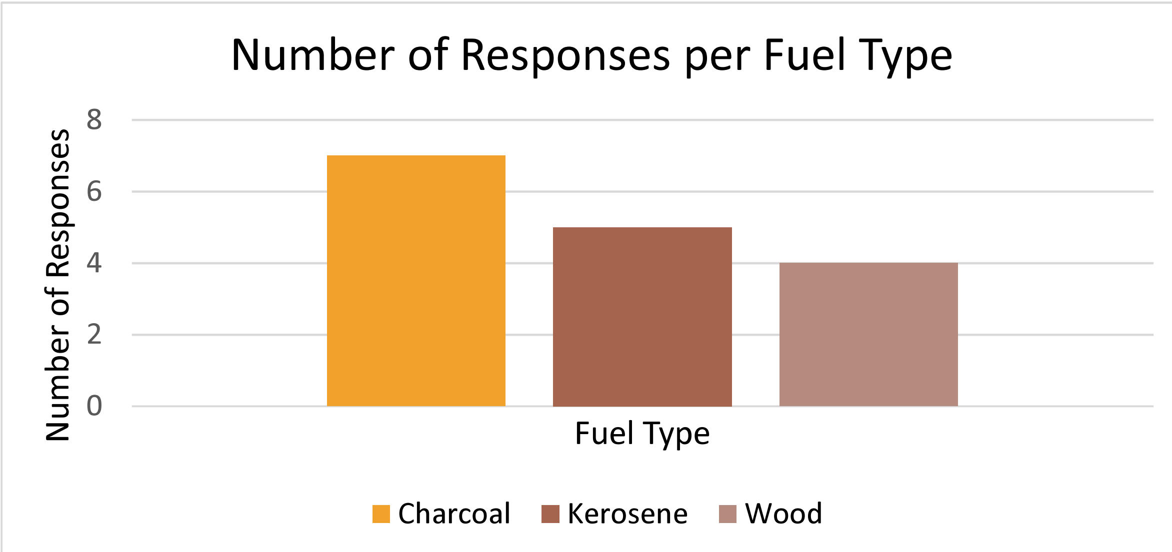

FIGURE 3: CUSTOMER RESPONSE SUMMARY CHART

generally serve up to 5 people, charcoal stoves up to 10 people, and open fires up to 100 people if large pots are used. The stoves are usually located out in the open or in a separate structure from the family quarters. The fuel types used include kerosene, firewood, charcoal lumps, dry grass, and cow dung. The charcoal lumps were found to produce a hotter fire, reach maximum temperatures of 1400 degrees Fahrenheit, and emit significantly less smoke than wood. The fires are used for cooking, boiling, and self-heating purposes. To light a fire, matches, lighters, converging lenses, paper, and plastic are used. Due to deforestation and other geographical conditions, wood is very scarce in some regions. The women in these communities are left with no option but to travel long distances to collect substantial wood supplies for their families, which they then transport either as a pile on their heads or tied behind their backs. Smoke emanating from these fires is inhaled and is therefore a huge concern. Burns have been known to happen, and children playing around the fire are usually the victims. Materials such as sand, cement, clay (bricks), stones, scrap metal, wood, and mud can be found or bought at nearby markets for building.

The performance of these fires has been found to be subpar, resulting in lengthy cooking times. Furthermore, because fire intensity cannot be controlled, someone must continually be present to stoke the flames to keep the fire going. Flame strength and width in the stoves are often not enough to cook some meals or heat bigger and wider pots. Both stoves are fairly easy to operate. For the charcoal stove, charcoal must be added at the top of the stove. The stove itself has an opening underneath where paper or other easily combustible material can be lit with a match, which lights the charcoal above. For Kerosene stoves, one must simply strike a match and light the wicks.

At the end of the interview, each participant was asked what improvements the team could bring for a better cooking-stove experience for themselves and people in their communities. These responses are listed below:

- Design a stove where fire can easily be turned on for use and off after use

- Design a stove that can control fire intensity (that also has high flame strength)
- Design a stove that produces a smoke-less fire
- Design a stove with a way for users to have the knowledge for maintenance/upkeep.
- Design a stove with good-to-great fuel efficiency

2.5 Review of Standards and Specifications

In pursuit of optimal operating conditions, maximized stove performance, and user safety, Disaster Relief Solutions investigated four main components within its specification and standards research: USB charging, Perlite insulation, Type J and K thermocouples, and Stainless and Carbon steel. Other areas of research were considered but eliminated due to the small safety risk and minimal stove performance impact.[16]

2.5.1 ASTM E800 Smoke Testing Standard

The ASTM E800 Standard Guide for Measurement of Gases Present or Generated During Fires outlines best practices for the planning of smoke test processes and gives the primary test methods used to detect and measure amounts of various gases. It notes that preplanning must be used to identify the goals of the smoke testing and constraints of the testing environment. By determining the information desired from the measurements, an ideal method can be chosen. The standard outlines three methods of sampling carbon monoxide, the gas that Disaster Relief Solutions was investigating: Gas chromatography, infrared analysis, and electrochemical analysis. It summarizes the advantages and disadvantages of each method and gives examples of common applications. Finally, it stresses the importance of instrument calibration and a clear understanding of instrument response time to collect good smoke data.

2.5.2 USB Charging Standards

The USB 3.0 standards specify the default USB voltage to be 5 Volts, with an operating current of 2 Amps. Device charger current outputs vary according to the size of the target device, and modern devices draw only as much amperage as needed or as much as the charger can supply. The target device for DRS, an average cell phone, requires between 0.5 and 1.0 Amps of current while charging at 5V. This current range provides a target value for the DRS electricity generation system, and a maximum output voltage.[17]

[16] "Standard Guide for Measurement of Gases Present or Generated During Fires." *ASTM International - Standards Worldwide*, ASTM International, 2014, www.astm.org/Standards/E800.htm. Accessed Apr. 2017.
[17] Universal Serial Bus Power Delivery Specification Revision 2.0, Version 1.1. May 2015. PDF, Pg. 509. Available: http://www.usb.org/developers/docs/ Accessed March 2016

TABLE 1: PERLITE INSULATION SPECIFICATIONS

Composition	Apparent Density (kg/m^3)	Specific Heat (KJ/kg*C)	Thermal Conductivity (W/m*C)	Softening Point (Celsius)	Fusion Point (Celsius)
Siliceous volcanic rock (expanded)	40-170	.387	.138 (at482 C)	871-1093	1260-1343

See Appendix U for Material Safety Data Sheet

TABLE 2: THERMOCOUPLE SPECIFICATIONS[18]

Type	Wire Materials	Temperature Range (Celsius)	ANSI Standard Limits of error	Recommended Atmosphere	Wire Insulation Coloring
J	Iron (+), Constantan (-)	0-760	+/- 258K or 0.75% (greater)	Vacuum, inert, oxidizing or reducing	White, Red
K	Chromel (+), Alumel (-)	-200-1100	+/- 258K or 0.75% (greater)	Inert or oxidizing	Yellow, Red

TABLE 3: STEEL SPECIFICATION (API 579 SECTION 4.4.1 HIGH-TEMPERATURE OXIDATION.)

Type	Oxidization Temperature
Stainless	1500°F
Carbon	1000°F

2.6 Summary of Findings

After a literature review, preliminary build days and preliminary electrical tests, the team identified several areas in which they wanted to focus their testing for the semester.

2.6.1 Internal Geometry

From thorough review of literature relating to internal geometry, the team realized the significance of this aspect in a rocket stove. The key components that were analyzed from last year's report as well as other sources involved certain geometric ratios. The ratios that were examined most closely were the outlet diameter to chimney height ratio and the inlet to outlet area ratio. The optimal inlet to outlet area ratio that had been previously tested was 1:2.25. To conduct tests to determine the optimal ratio, last year's team used constant diameter pipe for the inlet and chimney and constructed several restrictor plates to control the effective airflow area. This technique was identified as a possible source of error and topic for future work. The

[18] "Temperature – Electromotive Force (EMF) Tables for Standardized Thermocouples." *Pyromation,* 1999. Available: http://www.pyromation.com/Downloads/Data/spec_1.pdf Accessed April 2017.

team's goal for this year was to analyze whether the same ratios would apply if the entire internal diameter of the rocket stove inlet and outlet were changed. This goal along with a focus on scalability provided a method of validating the previous year's results. The outlet diameter to chimney height ratio was accepted based on agreement between the literature review and reliable findings by last year's team.

2.6.2 Gasification

The literature review on the topic of gasification proved to be very enlightening.[19,20] Gasification is a manufacturing process that converts any material containing carbon—such as coal, petroleum coke, biomass, or waste—into synthesis gas (syngas).[21]According to various sources, adding a gasification component to the process of burning fuel is instrumental in lowering emissions and increasing fire efficiency. A good fire relies upon the proper amount of three substances: heat, fuel, and oxygen. This interaction is known as the fire triangle. The topic of gasification involves the oxygen aspect of the fire triangle. Oxygen is a key component that when mixed with super-heated vapors in the proper amounts spontaneously combusts with these vapors. This phenomenon occurs separate from the burning of the solid fuel. Smoke is the super-heated vapor that still has the potential to combust when given the right amount of oxygen. Several sources note that gasification usually takes place near the top of a stove. The team developed a test that effectively measured the efficiency and reduction of emissions that the gasification process has on a rocket stove.

2.6.3 Pot Accessories

To increase efficiency, the team analyzed a significant amount of literature to optimize fire effectiveness[22,23]. One component that did not directly improve fire performance but rather affected the cooking performance was the pot skirt. This cooking utensil enabled the flames from the fire of a rocket stove to be directed back to the pot. This allowed for a larger amount of heat to transfer to the pot, which in turn increased fire efficiency. This pot accessory, according to various sources, was invaluable to the performance of the cooking stove. The team decided to implement this basic principle of redirecting flames back to the pot by testing a pot skirt. Additionally, two methods of increasing heat transfer through surface contact with the pot were

[19] "Wood Combustion - FlameWorks - High Efficiency Hearth." Wood Burning Combustion. Flameworks, LLC, 2006. Available: http://heartheat.com/flameworksOLD/index_WoodComb.htm. Accessed Jan. 2017

[20] Aysen, Zaid. "Wood Stove Secondary Combustion." Brighthub Engineering. 07 Sept. 2010. Available: http://www.brighthubengineering.com/machine-design/86002-secondary-combustion-systems-for-wood-stoves/. Accessed Jan. 2017.

[21] "The Gasification and Syngas Technologies Council." *The Gasification Process » GSTC*, GTSC, www.gasification-syngas.org/technology/the-gasification-process/. Accessed Nov. 2016.

[22] Brayden, Mark, et al. "Design Principles for Wood Burning Cook Stoves." *Design Principles for Wood Burning Cook Stoves*, www.rocketstove.org/images/stories/design-principles-for-wood-burning-cook-stoves.pdf. Accessed Nov. 2016.

[23] Jetter, James J, and Peter Kariher. "Solid-Fuel Household Cook Stoves: Characterization of Performance and Emissions." *Design Principles for Wood Burning Cook Stoves*, vol. 32, no. 2, 27 Sept. 2007, pp. 294–305. Available: http://doi.org/10.1016/j.biombioe.2008.05.014. Accessed Oct. 2016.

constructed and tested. Efficiently transferring heat from the fire to the pot is one of the team's main goals.

2.6.4 TEG

As a part the team's goal to generate electrical power from the stove's thermal energy, the electrical subteam reviewed several datasheets for TEG's to gain insight into the temperature requirements for various devices. In reviewing the data, it was determined that the maximum hot side temperature for all but high price devices was about 330 °C. This temperature is too low for the standard flame temperature generated by the stoves. From this it was determined that a method of allowing only a portion of the heat to reach the TEG must be selected. The final method reached was to use a purchased device designed to convert heat from a Sterno™ fuel can into electricity and modify the device so that it received a regulated amount heat from a rocket stove. The chosen method of regulation was to use an auto-adjusting air duct utilizing a bi-metallic strip of metal to turn a restriction flap.

2.6.5 In-ground Stove

Part of the scope of the team's project is to design a stove that can be easily deployable in disaster areas and situations. To produce the best in-ground stove the team took the ratios that were acquired through the testing of the different components of the above ground stove such as the ratio of inlet to outlet diameter to stack height (1:1.5:4.5). The team ran multiple tests on the in-ground stove to ensure that it was working the same as a rocket stove, as in using the Venturi effect to create a pressure void below the grate and pull the air in quickly to create a cleaner burn.

3 Clarification of Individual Project Assignment

3.1 General Overview

Disaster Relief Solutions is committed to researching and disseminating information on rocket stove optimization and applications. The team is seeking to discover keys to rocket stove performance by heuristically testing stove optimal ratios between air inlet and chimney outlet dimensions. Additionally, the team recognizes the need for highly efficient fires in disaster situations and developing countries. The team therefore tested the use of a secondary burn air inlet to boost overall fire performance. Both tests were conducted using stoves designed and fabricated by the team and industry-standard full factorial Design of Experiments (DOE) test methods. The team also set a goal of capturing the heat from the stove, converting it into electricity using thermoelectric generators (TEG), and therefore implemented multiple test concepts toward that end. The data from stove research allowed the team to publish technical guides for use in disaster situations and developing countries, as well as test and optimize a simple, in-ground approach to a rocket stove.

3.2 Relationship of Individual Project Assignment to Overall Project

3.2.1 Nathan Hughes

As Team Lead, Nathan worked to help set vision and direction for the team as well as worked closely with the stove team throughout the DOE design and testing processes. He served as a liaison between the team and Dr. Anson, the faculty sponsor, while coordinating meetings, agendas, and rosters and assisting with administrative needs. He led the bi-weekly DRS team meetings by preparing agendas and ensuring that subteam progress reports translated into action items and individual tasks for the subsequent week. Nathan worked with each member of the team to pull together the PowerPoint presentations for the team's end-of-semester reports, and helped as a speaker during these presentations.

3.2.2 Taber Miyauchi

The role that Taber Miyauchi undertook was Stove subteam Lead. His primary function was to oversee the construction, design of experiments (DOE) and execution of testing, which led to him presenting results at the conclusion of the year. Taber had a strong influence in what was going to be tested on the stove and how things were going to be tested. After much discussion, Taber and his subteam came up with ways to test inlet/outlet interaction effects, gasification effects with response variables of ramp rate of water temperature and carbon monoxide emission. Taber delegated various tasks to his subteam, trying to play to their strengths, to ensure that the project was executed successfully. He also brought the team together when tests needed to be conducted so that everyone knew the procedures. When data was collected, Taber helped analyze the results and draw conclusions.

3.2.3 Mark Claypool

Mark served on the stove design subteam contributing to multiple areas of the project. One of the first areas involved investigating stove insulation for the team. Several simulations were conducted using COMSOL, a finite element analysis software, to determine the optimal insulation wall thickness and stove shape. Along with his simulation work, Mark also performed heat transfer calculations to validate the insulation models. He also assisted the team in the fabrication process for the various test stoves. After construction was completed, he helped develop a LabVIEW program to monitor and record the temperature of the different stoves. This also allowed him to work with the NI DAQ as well as the thermocouples used in the measuring process. Mark also helped the electrical team conduct preliminary temperature tests on the thermoelectric generator’s stand. He assisted with the rebuild of the previous year's team stove as well as helped construct and test the gasification system.

3.2.4 Sean Eldridge

Sean served on the stove subteam, assisting with stove DOEs, construction, and stove testing. As a welding engineer, he assisted with creating welds where they were needed and provided insight on materials to be used for stove parts. He has helped the electrical team with material selection and construction of the TEG testing components. Sean was also in charge of the

PowerPoint slide transitions during both presentations, knowing when to advance and what hidden slides to jump to when relevant questions were asked.

3.2.5 Hunter Rose

Hunter played the role of member of the stove subteam. Hunter, along with the rest of the stove subteam, brainstormed ideas about what and how to test the various aspects of this year's stove design. This involved all the testing done by the stove subteam, including inlet/outlet ratio, gasification, insulation, and pot accessories. He helped complete testing of the various aspects of the design of experiments and analyze the collected data. Additionally, he used his experience with SolidWorks to design models for the presentations and for reference. He also used his photography skills and knowledge of Photoshop to keep a visual log of work completed, progress throughout the year, and has been responsible for acquiring pictures and graphics to be used for the presentations and final report.

3.2.6 Samuel Beans

Samuel was the team lead for the electrical subteam. With being an electrical engineering major, Samuel's leading role was to use his electrical knowledge and experience to help guide the electrical team to accomplish their goals. He worked directly with the team lead, Nathan, to keep him updated on where the electrical subteam was in their progress. Along with guiding the team, Samuel took part in the subteam experiments and research. With being a team lead, Samuel was also in charge of preparing and presenting a progress report in the team’s bi-weekly meetings.

3.2.7 Jared Wende

Jared was a member of the electrical subteam as an electrical engineering technology major. Jared's primary contributions to the subteam include the selection of TEG modules for testing, design and construction of the voltage regulation circuit, participation in testing days, and providing ideas for advancement of experimentation. Jared served as the team's Financial Controller, managing the team budget and refunds. Jared also performed any other tasks required by the subteam and provided insight during full team meetings.

3.2.8 Evan Boone

Evan was a member of the electrical subteam. As a mechanical engineer on the team, Evan contributed to experiment design for the electrical subteam, and provided the subteam with the design of the TERSEC (Temperature Regulation System for Electrical Components). The TERSEC allowed the TEG’s to be used with any rocket stove and avoid overheating. Evan also used his mechanical knowledge to determine the design and material choices for the TEG-stove interface. Evan used his electrical knowledge to assist the electrical subteam and provide ideas for experimentation. Evan also served as the liaison between the electrical subteam and the LeTourneau science department for scheduling and organizing lab experiments.

3.2.9 Justin Hevrin

Justin was the team lead for the Field Expediency subteam. Justin determined when team meetings would take place and what the overall vision for the team would be. As a member of Field Expediency, he helped obtain the Voice of the Customer through interviews, designed and built an in-ground stove, and design and built an in-ground stove support system for easy deployment in disaster situations. Justin contributed to the whole team by having team updates ready for the bi-weekly meetings, worked with the rest of the Field Expediency subteam to design the brochure and informational board for the team, and assisted the stove subteam in the testing that they performed. He additionally worked with the Field Expediency subteam to create pictorial and technical rocket stove design guides. He also worked on the final report and put together the Field Expediency portion of the final presentation.

3.2.10 Brandon Farrar

Brandon was a member of the Field Expediency subteam. Brandon worked with the field expediency team to build and test an in-ground stove. He worked on the design of the technical publications including the technical and pictorial instructional pamphlet. Brandon headed up much of the team publication design work including the PowerPoint presentation template, the display table, and the team pamphlet and poster. He also communicated with the team and members to structure and assemble the final report.

3.2.11 Lionel Tchekane

Lionel was a member of the Field Expediency subteam. Lionel, along with other members of the subteam, acted as a mediator between research within the team and real world applications. Given his standing as an international student and his knowledge of developing countries, Lionel's main responsibility was to provide the Voice of the Customer which included interviewing people with stove experiences and translating these answers into data to be used by the stove subteam. Lionel also participated in the construction and testing of an in-ground stove as well as information dissemination in the form of a pictorial informational pamphlet and technical guide. Furthermore, he assisted the stove team in testing and worked on editing the final project report.

3.3 Key Project Stakeholders

The key project stakeholders are listed below:

- Dr. Anson (Faculty Advisor): Dr. Anson oversees the project and is funding it from his research budget.
- Disaster victims in need.
- Developing countries and missional applications where cooking and sanitary water are a daily problem.

3.4 Requirements and Constraints

TABLE 4: REQUIREMENTS AND CONSTRAINTS

Test Stove	
Criteria	**Constraints**
Cooks food	Cooking does not hamper stove efficiency
Energy-efficient	Produces little smoke
Adjustable parameters	Withstands temperatures up to 1200°C
Precise control of parameters	Safe to briefly touch
Easily controlled operation	Allows access to burn chamber for thermocouples
Repeatable performance	Ash cannot interfere with stove operation
Continuous performance	
Power Generation	
Criteria	**Constraints**
Charges a cell phone	Powered by heat of stove
	Produces 2.5W +
	Produces steady power
	Does not hamper cooking
	Survives heat near stove
In-ground Stove	
Criteria	**Constraints**
Energy-efficient	Produces little smoke
Easily built	Requires few tools to be built

3.5 Specifications and Target Values

The Disaster Relief Solutions Rocket Stove project is a developmental project where the team is seeking to learn more about a rocket stove and optimize a stove design. There are few numerical specifications for what the stove must achieve, however, the stove needs to burn fuel cleanly and completely to reduce pollution and burn hot enough to provide a convenient cooking surface while using minimal fuel. The electrical side of the project plans to deliver 5 Volts and 2.5 Watts of USB power to ensure quick and reliable phone charging. The field expediency portion of the project looks to develop a stove that can be easily built in disaster situations and developing countries as well as design an easily understandable design guide.

4 Assessment of Consequential Effects

To address the sustainability and the ethical considerations of the project, each member of the team wrote about the sustainability of the project and any ethical considerations pertaining to the goals and results of the project. Each team member summarized personal remarks for this section to fulfill ABET requirements for an accredited engineering degree from LeTourneau University.

4.1 Sustainability Assessment

4.1.1 Nathan Hughes

Disaster Relief Solutions has as its primary goal the provision of heat and energy to situations with limited resources. These contexts include disaster scenarios or developing countries where construction materials and combustibles can be scarce. Thus, this project seeks to increase the efficiency of energy conversion from wood to useful heat as well as drastically reduce the carcinogen output of cook fires. A key emphasis of this year's project was reduction of carbon monoxide emissions by creating a secondary burn in the rocket stove chimney. These two areas of the team's work have major environmental benefits and provide options to reduce biomass consumption. During testing processes, the team is using recyclable materials, largely steel and aluminum, for test stoves as much as possible. Further, many of the materials used by the previous DRS team are being repurposed for updated test stoves to eliminate the need for additional resources. Thus, both in current testing and team goals, Disaster Relief Solutions is working toward excellent stewardship of resources and optimal energy conversion using rocket stove principles.

4.1.2 Taber Miyauchi

This project shows excellent sustainability as the current rocket stove used for testing is made from recycled stainless steel. This will ensure that the fire during future testing will not corrode and render the stove ineffective. However, part of this year's project is not as sustainable because verification tests utilized specimens made from concrete and buckets. These concrete stoves will slowly become unusable and just break down into chunks of concrete and the buckets must be scrapped after serving the purpose of a mold. Nevertheless, the benefit of using concrete is that it is cheap and does not leave a large carbon footprint. Overall, the emissions from rocket stoves have a smaller carbon footprint than regular campfires because of the gasification effect and less wood is burned because the fire is more efficient in directing heat towards a specific point. Also, carbon monoxide, which is a harmful gas, is reduced by the gasification effect. Lastly, the impact of reducing the amount of smoke emitted may be life-changing if people in developing countries implement DRS's design information.

4.1.3 Mark Claypool

This project entails a vast amount of design work combined with testing to discover a rocket stove's optimal fire performance and efficiency. The underlying principle for this project is to produce safer, cleaner cooking options for disaster situations as well as for developing countries. The scope of this project is not just limited to improving the cooking experience, but rather, it is an in-depth examination into the methods of reducing fuel and harmful emissions without sacrificing stove performance. Lowering the amount of fuel of a stove allows the team to provide a sustainable solution. Maximizing fire efficiency is achieved by incorporating several different stove accessories into a rocket stove. A gasification pipe combined with a pot skirt provide a more efficient and effective means of combusting fuel. Carbon monoxide is one harmful emission that is reduced using a gasification pipe. Using renewable fuel sources such as wood have allowed the team to have a minimal impact upon the environment. The team has also integrated a system that uses the excess heat from the stove to power small electrical devices. Thermoelectric generators are the tools that accomplish this amazing phenomenon. Overall, this project not only provides a sustainable and efficient combustion process for a rocket stove, but it also effectively addresses the need to maximize stove performance.

4.1.4 Sean Eldridge

The DRS team focused on improving stove performance and efficiency, as well as furthering the electrical generation for USB charging. Rocket stoves continually show their value in disaster scenarios and in developing countries. The idea of a group of engineers studying the concepts of a rocket stove and making adjustments shows that there are always improvements that can be made for such a device. An area that rocket stoves show huge demand are in developing countries where fuel, such as charcoal and wood, is limited, thus demanding optimum performance and efficiency. Next to optimum efficiency is the idea of an affordable and dependable stove. Families in developing countries considering switching to rocket stoves for preparing meals are likely not looking for a multi-hundred-dollar electric stove. They need something cheap, but also as mentioned earlier, reliable, maintainable, and efficient.

Future DRS members must always remember pollution is a critical concept when utilizing a stove. People cannot always cook meals in the outdoors due to varying weather conditions and in some countries life threatening environments where just being seen by potential roving enemies could lead to serious or fatal injuries. Cooking indoors must be an option with rocket stoves.

4.1.5 Hunter Rose

This project seeks to improve the efficiency and performance of the stoves used in developing countries and disaster situations. This is important because finding fuel in developing countries can be a dangerous task and the less fuel is used, the less environmental impact the stove would create. In addition to this, Disaster Relief Solutions is attempting to produce a cleaner burning stove which releases less chemicals and emissions into the atmosphere. This year, the team is also furthering the ability of the rocket stove to produce electrical power to charge small electronic devices such as cell phones being useful to make calls for help in emergency situations. This is energy that would otherwise be lost or unusable. Lastly, one of the DRS subteams is experimenting with building rocket stoves from materials easily obtainable in developing countries or disaster situations, such as an in-ground stove, which can be built with nothing but one's hands.

4.1.6 Samuel Beans

The nature of this project is to increase the efficiency of a fire and generate electricity from the abundant heat produced. The stove elements of the project are somewhat sustainable as the one aim of the project is to have a design that can be sent around the world describing/showing how a rocket stove can be built using materials commonly available. For the electrical elements of the project, however, this was not the case. The method chosen for generating electricity from heat was a thermoelectric generator (TEG). This technology has only been around for around 40 years and must be built using modern machinery. These TEG's contain lead and other materials that can be harmful to the environment. With the harmful materials and modern machinery needed to build, the electrical generation of this project is not very sustainable. This does not mean that new and better TEG's may be developed or something completely different than a TEG may be used. However, for now, a TEG must be used.

4.1.7 Jared Wende

The project focus of Disaster Relief Solutions is intended to allow the team to produce a rocket stove that will aid disaster areas and developing countries. The primary method to accomplish this is to increase the efficiency of the fire. In doing so, the team intends to decrease the amount of fuel required to accomplish the same goals. This results in less environmental cost to provide the fuel. From an electrical point of view, TEGs are still a relatively new technology. As such, they are not yet confirmed to have a positive net environmental impact when considering the benefits of electrical generation versus environmental impact. Until further research is conducted, their sustainability will be in question.

4.1.8 Evan Boone

From an electrical standpoint, the materials used for electrical generation are currently not very sustainable. Since the TEG is still a cutting-edge technology, there are very few semiconductors that are optimal for electrical generation. Thus, the elements in some of the compounds are hazardous to health and the environment if disposed of incorrectly, such as lead telluride (PbTe). If the demand for TEG's increases, which it is trending towards, new compounds will likely be developed that are better for sustainability. In the meantime, TEG's with harmful compounds should not be sent overseas to areas that do not have the methods for their proper disposal.

4.1.9 Justin Hevrin

Sustainability in regard to field expediency comes from the preservation and dissemination of the design information. The in-ground stove uses minimal materials to create a fire that burns more efficiently than a traditional three stone fire and protects the fire from the effects of high winds. The use of minimal materials to build the stove means that the in-ground stove can be deployed in any situation. In addition, not using many materials means less waste and change in the overall environment in which the stove is deployed. An example of a deployable in-ground stove is one fashioned from a fire extinguisher. The use of a fire extinguisher is just one example of using a source that would be found in a disaster situation to create an in-ground stove. Both developments from this project show the sustainability of not only the stove that is deployed but the information that was used to create that stove. Therefore, sustaining the design information allows for further work in the field of rocket stove design and provides a better solution for fire for those in disaster situations. The in-ground stove uses minimal materials to create a fire that burns more efficiently than a traditional three stone fire and protects the fire from the effects of high winds. The use of minimal materials to build the stove means that the in-ground stove can be deployed in any situation. In addition, not using many materials means less waste and change in the overall environment in which the stove is deployed. An example of a deployable in-ground stove is one fashioned from a fire extinguisher. The use of a fire extinguisher is just one example of using a source that would be found in a disaster situation to create an in-ground stove. Both developments from this project show the sustainability of the ability to build a field expedient rocket stove and the information used to create the stove. Therefore, sustaining the design information allows for further work in the field of rocket stove design and provides a better solution for fire for those in disaster situations.

4.1.10 Brandon Farrar

The team has worked to provide a solution for heating and energy production in a way which uses a minimal amount of materials and can be used even in remote or desolate locations. The goal of the project is to create an efficient design for a rocket stove which allows for less fuel to be used for an optimal burn. The team has worked to use many recycled materials by reusing scrap metals. The in-ground stove also incorporates a design which requires few materials and provides virtually no ill effects on the environment to build. The main components of the project that were least sustainable were the concrete stoves and the TEG. However, with future developments, designs for testing and implementation can be improved for sustaining the environment.

4.1.11 Lionel Tchekane

DRS is looking at attainable ways to make the stove project a sustainable one. A sizable quantity of the metal used for our stove construction was obtained at scrap yards and therefore shows efforts towards sustainability. Unfortunately, wood is the main fuel source used and it is common knowledge that deforestation is a problem worldwide. DRS plans to provide an informational guide that can be used in disaster situations worldwide. Nevertheless, there is no guarantee that people in given disaster situations will have access to the resources available to and used by the team. The in-ground stove tested by the Field Expediency subteam essentially has minimal negative effects on the environment as the ground (soil) is used to try to create and provide a fire chamber that burns efficiently and releases low levels of CO and other pollutants into the environment. If such a stove was to be used in a disaster situation, the world and atmosphere would be better for it. More work will continue to be done either by future DRS teams to address the problem of pollution for the people in developing countries and disaster situations.

4.2 Professional and Ethical Considerations

4.2.1 Nathan Hughes

The core motivation of this project is the safety and welfare of individuals in disaster situations and developing countries. This harmonizes with professional engineering ethics as it places the value on the individual, not the product, and seeks to promote health. The most profound effects of this project on improving quality of life are found in its usefulness in meeting essential needs for life such as clean water and heat, as well as reducing risk of injury or assault for those who might use this stove in a disaster area or warzone. This project also reduces risks of burns from exposed cook fires and harmful effects of smoke inhalation by creating a more efficient, clean-burning stove. With the welfare of the customer in mind, Disaster Relief Solutions has invested in a tool that is fundamentally driven by high ethical standards.

4.2.2 Taber Miyauchi

The ethical consideration of this project does not raise major concerns. Based off the first fundamental canon of the NSPE Code of Ethics, this project is driven by the motivation to increase the health, safety, and welfare of its user. The rocket stove that the team is designing reduces the amount of smoke that users could potentially inhale. Additionally, it increases users' safety in developing countries by reducing the amount of wood that needs to be burned. This in turn allows women and children to stay closer to camp and not have to travel out into dangerous and war-torn areas to collect wood. Furthermore, the electrical charging devices increase the welfare of people in rural areas by giving them a way to charge their phone right where they are living and not have to travel to cities to find a charging port.

4.2.3 Mark Claypool

Considering the ethical ramifications has been a paramount part of this project. One consideration is how the team's research and documentation will be made available to the public. The goal of this project is to provide information in regard to the method of designing sustainable, efficient, and high performing stoves free of charge. This will allow developing countries and those in disaster situations to have a means of addressing the essential, basic human needs for survival. The betterment of society is the underlying purpose for this project. Also, the team has made the issue of safety of highest importance. The lens through which this project has been viewed has had the wellbeing and protection of those potentially using this information continually in mind throughout the design and testing process. This project is not only focused on providing safe and reliable solutions to the world, but it also bears in mind the necessity of maintaining a safe environment throughout the design and experimentation process. Overall, fire safety is a critical consideration in observing ethical and professional practices.

4.2.4 Sean Eldridge

Some professional and ethical issues DRS hopes to address this year regarding rocket stoves are minimizing fuel consumption, cleaner burning fires, and availability to charge electrical devices during stove heating or cooking processes. Many times, in developing countries, the environment outside of residence is often dangerous socially and naturally. To reduce this exposure, many tests have been performed to determine optimal fuel feed rate, allowing the stove to function effectively while also minimizing the fuel consumption for people in these types of environments. For indoor use, rocket stoves must produce little or no smoke pollution, decreasing or eliminating the chances of physical illnesses. Therefore, analysis of CO emissions has been conducted, determining the best method of gasification, to increase the effectiveness of secondary burning inside the stove. The ability to charge electrical devices using only the heat produced from the stove is another important need in developing countries. Most people must travel to a secondary source, besides their home, to charge devices such as cellular phones.

With a rocket stove offering thermoelectrical USB charging, the need to travel to secondary sources is minimized or eliminated completely.

4.2.5 Hunter Rose

The NSPE Code of Ethics reads that chief among an engineer's concerns should be safety, health, and public welfare. Disaster Relief Solutions is attempting to improve all three of these with this year's project. Safety is being improved by requiring less fuel, which will allow people to stay closer to their homes and close to safety. Health is being improved by creating a cleaner, more efficient stove which releases less toxins into the air. This significantly reduces the amount of smoke inhalation that one experiences using a normal fire. Welfare of the public is being improved by designing a stove that burns superior and more efficiently than their current means of cooking. In addition, the team is attempting to incorporate electrical device charging which will increase safety, by being able to charge a cell phone to call for help, and welfare, by accomplishing this with energy that would otherwise be lost.

4.2.6 Samuel Beans

The most important part of any engineer's job is safety. The first fundamental canon of the NSPE Code of Ethics is about the safety, welfare, and health of the public. The motivation for the DRS project was set with this in mind. The team is designing a rocket stove that will be more efficient and safe than any current methods. By creating a stove that will allow a cleaner and more efficient burn, Disaster Relief Solutions will be working to improve the safety, welfare, and health of the public. Along with being more efficient and safe, an electrical generation aspect is also being included. This will increase the welfare and safety of the public as they will have access to electricity which may not be available otherwise. When people have access to electricity they can charge their phone which could be the difference between life and death during a disaster situation.

4.2.7 Jared Wende

The fundamental purpose of Disaster Relief Solutions is to improve the cooking experience for people in developing countries or disaster situation. The first point of the NSPE Code of Ethics states that engineers are to "hold paramount the safety, health, and welfare of the public." The primary concern of the team is improvement of living conditions and is, as such, not in the least an ethical concern. In addition to this, the individual goals of the team reflect that of the primary. The intent to increase fuel efficiency allows for the decreased usage of resources while the electrical generation allows the user to make use of energy that would have otherwise been forfeit.

4.2.8 Evan Boone

According to the first canon of the NSPE Code of Ethics, engineers shall hold paramount the safety, health, and welfare of the public. Considering the goal of this project, the team's utmost priority is to satisfy this first canon. The rocket stove was designed in such a manner as to increase the safety, health, and welfare of its user. It accomplishes safety by providing a more efficient stove, which reduces time spent gathering fuel, which can be very dangerous in many areas of developing countries. It accomplishes health by completely combusting particulate smoke, which is hazardous to the lungs. Lastly it accomplishes welfare by providing a way for the user to charge their electronic devices using energy that would be lost as waste heat.

4.2.9 Justin Hevrin

The ethical demand to do what is right for those in need has been a driving force for this team. It has been the desire of DRS to improve the living situation of those both in developing countries and in disaster situations. To do this, DRS planned to not only design a cleaner, more fuel-efficient stove that will improve the quality of life in those situations, but also distribute its findings to be able to have the greatest impact on the improvement of human life. The starting point for DRS is to improve the living situation of the women and children in developing countries by providing them a stove that is safe, easy to use, and does not require the same amount of material to burn as a standard stove does. This means that people in these countries will not have to travel as far to acquire the material needed for the stove. To improve the living situation of those in disaster situations, DRS has developed designs that can be applied to a variety of building materials to achieve the same effect of a standard rocket stove. This work by DRS will improve the living situation of those in need.

4.2.10 Brandon Farrar

The DRS project revolves around improving the welfare of the user. The project falls well within the standards of ethical considerations. The team is trying to find ways to easily and safely improve the cooking and heating process for various people groups. The purpose of using and improving the rocket stove is to increase safety by reducing the likelihood of illness caused by smoke inhalation as well as reducing the amount of fuel needed to operate the stove. The latter means that residents will not have to travel into potentially dangerous areas as often to retrieve fuel for the stove. Overall, the team will maintain and improve the safety of the target market with this project.

4.2.11 Lionel Tchekane

The ethical factors of the stove project definitely weighed on the decisions made and the direction that the team took. Lionel is someone who has seen women travel long distances to gather wood for fires and seen children and their mothers suffer from smoke inhalation. The challenge that DRS has embraced is working to reduce the health hazards associated with three stone fires by providing a stove that burns efficiently and therefore reduces smoke and other pollutants. Better fuel efficiency also means that women will no longer have to travel long distances and risk their lives to gather wood. The stove project does not violate any of the 6 fundamental cannons summarized by NSPE. Instead, the goals and work of DRS make the environment better and the users safer while honoring the rules of engineering ethics.

5 Individual Design Work

5.1 Pot accessories

5.1.1 Introduction

After the literature review, the team identified one of the factors that affected the quality of the rocket stove to be pot accessories. Pot accessories include the method of supporting the pot on top of the rocket stove (pot stand) and an enclosure around the pot to retain heat (pot skirt). The literature review suggested that increased cooking performance could be achieved by keeping the flames close to the sides of the pot to retain the heat[9]. A pot enclosure was the logical and simple way to do this.

5.1.2 Design Solution Development

The two design ideas formulated for the pot stand included a simple cross bracing and a heat exchanger. These two designs were selected based off contact area and construction complexity. Theoretically, increased contact area with flame and with the pot would increase the amount of heat input into the pot.

The main consideration for constructing the pot skirt was that it must be neither too tight around the pot to restrict air flow nor too loose around the pot to lose any effect. This can be achieved by keeping the area of the chimney outlet, shown in yellow below, equal to the area between the pot and pot skirt, seen below in green. When area B (yellow) = area C (green), the system allows for unrestricted flow of heat around the pot by maintaining the same effective flowrate. During construction, the team found an ideal aluminum pipe and steel pot that fit these parameters.

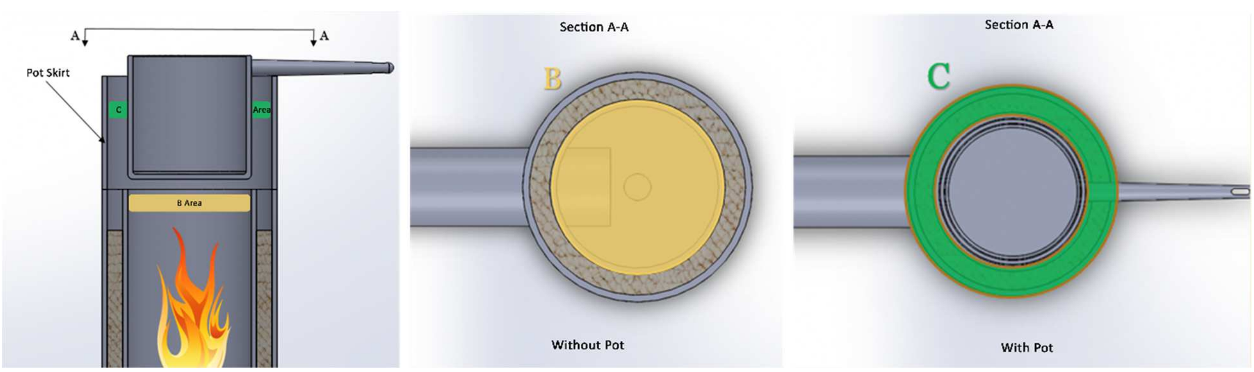

FIGURE 4: POT SKIRT SIZING ILLUSTRATION

5.1.3 Embodiment of Solution

The selection of material was mainly based off of the manufacturability and ability to withstand heat. The cross bracing and the heat exchanger stands were both made out of steel. The main manufacturing challenges came from the heat exchangers. The main idea behind these components focused on increasing the contact area with the flame as much as possible. To achieve this, a thin metal strip was bent as seen in Figure 5. However, during the manufacturing of the heat exchangers, the metal bender that was being used could not create U-bends that were spaced less than a quarter inch apart, which became the driving factor behind why the heat exchanger cross sections were so widely spaced.

FIGURE 5: HEAT EXCHANGER CONCEPT IN TESTING

The cross bracing rod stand was an accessory built by the previous year's team. It used a carbon steel plate with a 6" diameter hole cut through the middle as the foundation for a support surface made from welded steel rod. (Figure 6) The size for the pot enclosure was determined using the area of the chimney and the diameter of the standard testing pot. For a 6" chimney and resulting area of 28.27 in^2, the distance between the pot and enclosure needed to be about 1". An aluminum pipe was found that fit very close to meeting the requirements of this cross-sectional area. (Figure 6)

5.1.4 Assessment of Embodiment

The cross bracing and the pot enclosure were fabricated as envisioned. However, the heat exchangers were slightly different than expected because of the methods used for manufacturing. The spacing between the vertical columns were spaced wider than originally intended. Additionally, the heat exchangers did not make full contact with the bottom of the pot, which reduced their heat transfer effectiveness. (Figure 7) If the team were to test with these again, hi-temperature epoxy or weldments should be used to join the pot and the heat exchangers together.

FIGURE 6: ROD STAND CONCEPT (LEFT) AND POT ENCLOSURE (RIGHT)

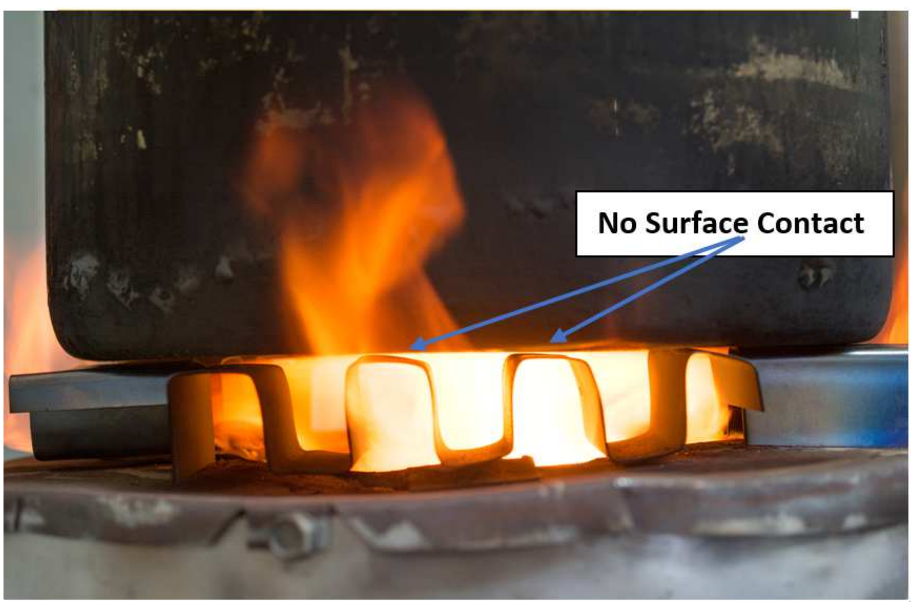

FIGURE 7: HEAT EXCHANGER DETAIL

5.1.5 Assessment and Validation of Concept

The manufacturing of the pot accessories illustrated the feasibility challenges that would be present in a developing country or disaster situation. The pot enclosure and the cross-bracing stand were both very easy to manufacture and performed exceptionally well in testing, proving their effective contribution to any rocket stove. On the other hand, the heat exchangers were difficult to manufacture and performed poorly. This outcome proved that the simple designs are more effective in developing countries. The testing of these concepts is summarized in Section 6.1.2.

5.2 Internal geometry

5.2.1 Introduction

To confirm the concept of the 1:2.25 optimal ratio of the inlet area to outlet area of the stove, the team decided to construct several concrete stoves to conduct a Design of Experiments (DOE) procedure. This ratio is one of the most fundamental parameters of rocket stove design and profoundly affects stove performance. The testing with concrete stoves sought to build upon and verify the work of the 2015-2016 Disaster Relief Solutions team.

5.2.2 Design Solution

The need for varying internal geometry led the team to consider either making multiple stoves or a single stove with interchangeable internal piping. The idea of making several stoves was chosen as the simplest and most cost-effective concept. Time was a key constraint that drove the need to manufacture several stoves quickly, each with different inlet, outlet, and height combinations. Since each stove required different combination of dimensions, a standard mold could not be used. The longevity of the materials mattered very little because of the limited use the stoves would endure. After some research, the team found that concrete is a common rocket stove material.[24] This material was chosen since it allows for quick manufacturing of stoves and easy customization of different geometries.

5.2.3 Detailed Solution Development

After determining to use concrete stoves to embody the design, the team developed a design plan with simple dimensions that could be adapted for each stove. PVC pipe was chosen to create the inlet and outlet cavities as PVC is cheap, easily obtainable, varies in size, and is easy to fabricate. The team also chose to use 5-gallon buckets as the outside forms of the stove molds as they are cheap and provide a consistent size for each stove.

Next, the DOE design was considered and determined which ratios to build and test. The previous DRS team determined that a 1:2.25 area ratio between the air inlet and outlet was

[24] Lonergan, Gene. "How to make a $12 Rocket Stove." Available: https://www.youtube.com/watch?v=aOZ7gJaqdtQ . Accessed Oct. 2016

ideal. The goal of testing with the concrete stoves was to verify this ratio by testing similar ratios. Testing of a 1:1 ratio was perceived as being additionally helpful as it would be the easiest ratio for people in developing countries or disaster situations to construct. To test a ratio only slightly different from the ideal, a 1:1.8 ratio was also planned. Lastly, to provide a comparative data point and test an anticipated poor performing stove, an additional stove was to have a ratio of 1:0.56.

5.2.4 Documentation of Embodiment

The concrete rocket stoves were constructed to the ratio specifications outlined above and can be seen in Figure 8. They underwent one major revision to extend the chimney height of each stove to match optimal dimensions, which can also be seen in the figure. These test stoves provided a reliable platform for the internal geometry Design of Experiments.

FIGURE 8: CONCRETE STOVES

5.2.5 Discussion of Embodiment Process

After concluding that concrete stoves best fulfilled the requirements for internal geometry testing, the team procured concrete, PVC pipe, and the other materials required and began fabrication. First, 45° angles were cut on the 1:1 ratio PVC pipe so that the angle at the joint would be exactly 90°. For the ratios that were not 1:1, a hole the size of the intake was cut into the bottom of the outlet PVC pipe. This enabled the insertion of the inlet directly into the bottom of the outlet to create the angle. (Figure 9) Measurements were taken from the bottom of the 5-gallon bucket for the placement of the inlet hole, which was cut to match the dimension of the inlet pipe. Next, concrete was poured into the bottom until it started to reach the height of the inlet hole. The inlet and outlet pipes were then placed into the bucket and the rest of the bucket was filled with concrete. After letting the concrete cure for 30 days, the PVC pipes were pulled out.

FIGURE 9: CONCRETE ROCKET STOVE CONSTRUCTION

The grate system used to raise the wood off the bottom of the stove was originally constructed as a flat, mesh piece at the top of the inlet, in the chimney. This also had to be revised as the stove performance was very dependent on where the fuel fell. It was decided to slope the grate so that all the fuel fell to the back of the burn chamber, but this proved to be ineffective as it did not lift the fuel off the bottom of the inlet or allow for the maximum air flow through the stove. Furthermore, it began to reduce the stove's stack effect. This design was also not very secure as the stoves began to heat up and expand the grate metal. Finally, a solution was reached by angling the grate to the back of the stove and using a support to lift it to the height of the top of the inlet. With this configuration, the fuel received excellent airflow and reliable stability.

5.2.6 Assessment of Embodiment

The team then recognized that the stoves would not all perform ideally as not all of them met the ideal outlet diameter to chimney height ratio of 1:3.5. Since all stoves needed to be taller than the 5-gallon buckets would allow, a second bucket was used on top of the first to extend the stove height. The bottom of this second bucket was removed and the shell was duct taped to the original bucket mold. A PVC pipe the size of the chimney was inserted into the chimney so that it protruded out the top of the upper bucket and served as the mold for the stove chimney. Concrete was poured into the upper bucket to surround the mold and allowed to cure for 30 days.

The embodiment of the design was different than originally intended as the final design had to add chimney height to meet the ideal outlet diameter to chimney height ratio. However, this modification did not prove to be much of a burden on the manufacturing process and eliminated a noise variable from the stove testing process.

5.2.7 Assessment and Validation of Concept

The concrete stoves proved to be a viable solution to the team's needs. By the end of the testing, some of the stoves had begun to crack, but none of them cracked enough to modify the results. The stoves were quick, easy, and cheap to construct, which is exactly the design specifications required of the internal geometry test stoves. Because of the consistent internal geometry in each stove, the team obtained more reliable test data and a better understanding of the field expedient uses of concrete stoves.

5.3 Insulation

5.3.1 Introduction

Heat retention is an essential concept to a rocket stove given that a hot stove burns more effectively given enough oxygen and fuel. One goal was to analyze different methods of retaining heat. This directly affects the third element of the fire triangle: heat. Insulating a rocket stove retains heat, which increases stove performance and efficiency. The shape of a rocket stove affects its performance as well. Examining both stove shape and insulation, enabled the team to effectively optimize a rocket stove's performance. While determining the best method for retaining heat by looking at stove shape and insulation, a focus had to be maintained regarding the practical constraints of the project. After considering the end user and available materials, the team began the process of improving heat retentive properties of a rocket stove. Two different shapes, a square and circle were analyzed and tested to determine the optimal cross-sectional shape of a rocket stove. The type and amount of insulation used was also examined.

5.3.2 Design Solution

Considering heat retention, the logical step was to analyze insulation properties. A wide range of insulation types were examined and researched. A few that stood out above the rest included vermiculite, pearlite, and a ceramic fiber blanket. The ceramic fiber blanket had the lowest thermal conductivity coefficient, which prohibits heat transfer by retaining heat. Because the thermal conductivity coefficient was 0.2 $Wm^{-1}K^{-1}$, the ceramic fiber blanket was clearly the greatest retainer of heat. Once this type of insulation was chosen, the process of determining the optimal stove shape began. A square and a circle were chosen as the two competing shapes because both were simple and straightforward to fabricate in disaster situations. Other shapes were considered, such as a triangle, but due to the impracticality of manufacturing these stoves, they were discarded. The insulation wall thickness was examined as a third aspect of heat retention. The goal of this study was to discover the optimal insulation wall thickness for a rocket stove.

5.3.3 Detailed Solution Development

To begin determining the optimal stove shape, a quantitative analysis was conducted on both the circle and square using COMSOL, a finite element analysis software. A one-dimensional analysis proved to be the best method for simulating the loss of heat. This visual study allowed the temperature distribution inside a rocket stove to be analyzed as seen in Figure 10.

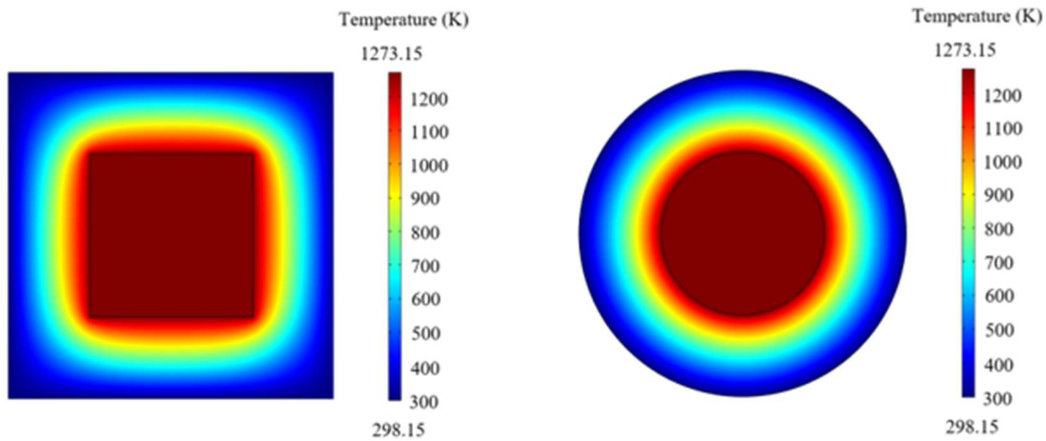

FIGURE 10: HEAT LOST FOR SQUARE DESIGN (LEFT) AND CIRCULAR DESIGN (RIGHT)

The internal and external temperatures were held constant in this simulation as well as the internal and external surface areas. The surface areas were held constant due to the three-dimensional nature of the rocket stove. The internal temperature was 1273.15 K, which is approximately the temperature value of a high performing rocket stove. The external temperature was 298.15 K, which is the average ambient room temperature. The results showed a wider temperature distribution in the square surface temperature plot as opposed to the circle. This observation led the team to conclude that the circle was the best heat retentive shape due to its thermal properties. This conclusion was affirmed by the fact that a circle has the largest consistent wall thickness when comparing it to other shapes such as a square. However, before a final conclusion could be drawn, heat transfer calculations were completed to validate both the observable and theoretical deductions. Appendix P provides an in-depth analysis of how the values were calculated. The results of the calculation showed that the circle lost 14% less heat than the square, which clearly indicated the circle as a superior shape. With this knowledge in mind, more heat transfer calculations were conducted to discover the optimal insulation wall thickness for the rocket stove. Appendix O provides a systematic process of how the calculations were obtained. A graphical representation of the different wall thicknesses which were tested can be seen in Figure 11 below.

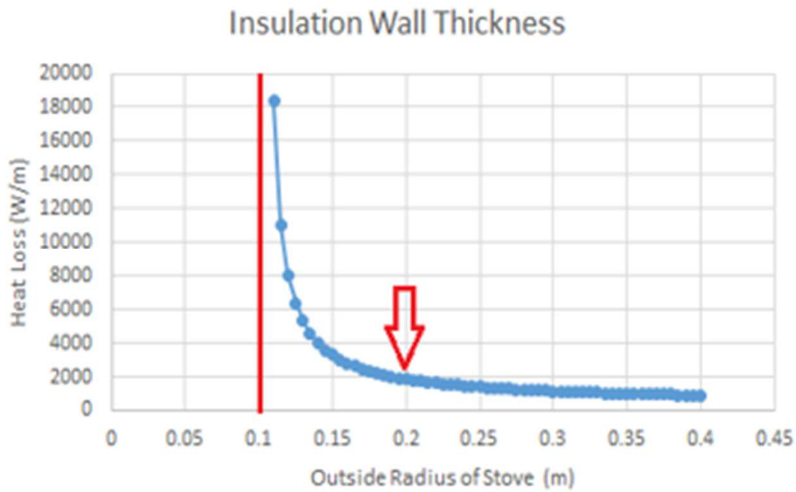

FIGURE 11: INSULATION WALL THICKNESS

The red line in the picture above represents the inner radius of the stove burn chamber while the arrow indicates the optimal outside stove radius. The graph portrays a systematic increase in the insulation wall thickness. The inner radius of the rocket stove was 0.1 meters while the first outside radius data point was 0.11 meters. The outside radius was increased by increments of 5 milimeters while the inner radius of the stove remained constant. The heat lost was an exponential function that decayed. The tested radius range was from 0.11 to 0.4 meters. These dimensional constraints were obtained from considering the practial implications of fabricating a rocket stove. An underlying insulation thickness ratio can be gleaned from this graphical representation of heat lost. A basic 2:1 outside to inside radius provides the greatest reduction in heat loss while maintaining reasonable design constraints. This ratio was an essential aspect to the rocket stove deisgn process. Overall, the calculations and simulation software provided an effective means of determining the optimal shape and practical thickness for retaining heat.

5.3.4 Embodiment of Solution

The team chose to focus on gasification and internal geometry rather than physically constructing and testing each of these insulation concepts. The topic of insulation provides an exellent opportunity for future work. However, both the insulation ratio and stove shape were implemented into the rebuild and construction process of the previous year team's rocket stove. Tests were not conducted on these two design solutions. Also, the type of insulation material was not applied due to time constraints. In summary, analyzing heat retention provides essential information to the project that will be fully implemented in the future.

5.4 Gasification

5.4.1 Introduction

Improving the efficiency and performance of the rocket stove by optimizing the fire triangle was one of the main goals of the project. To achieve this objective, the team analyzed one of the components of the fire triangle: oxygen. During preliminary testing, it was discovered that inserting a stream of air at the end of a chimney would sometimes produce a flame. (Figure 12) Researching this phenomenon opened the door to another area of potential testing. A secondary burn is created when the proper amount of oxygen, fuel, and heat are combined. This secondary burn, known as gasification, reduces harmful emissions by re-combusting the smoke. The goal for this part of the project was to improve fire performance and efficiency by harnessing the gasification effect.

FIGURE 12: PRELIMINARY TEST STOVE WITH GASIFICATION FLAMES

5.4.2 Design Solution

To analyze the secondary burn of the rocket stove, a method of feeding additional air into the burn chamber was developed. The team's goal as the brainstorming design process began was to harness the gasification phenomena by inserting oxygen above the fire to produce the right mixture of fuel to air for combustion. The first design solution that the team considered involved using the concrete stoves. However, after further examination, the team decided to rebuild the previous year's stove for this area of tests. This was due to the lack of durability of the concrete stoves. Some of them had cracked from the high temperature tests that were completed previously in these stoves.

Once the decision was made to repair the previous year's stove, determining the best method of inserting air into the rocket stove was begun. Two methods were developed for the gasification stoves. The first consisted of a radial gasification method. Outside air would come in from a gap between the insulation and the burn chamber. (Figure 13) This method was discarded due to the impracticality of being able to control the flow rate as well as the location of the inserted air.

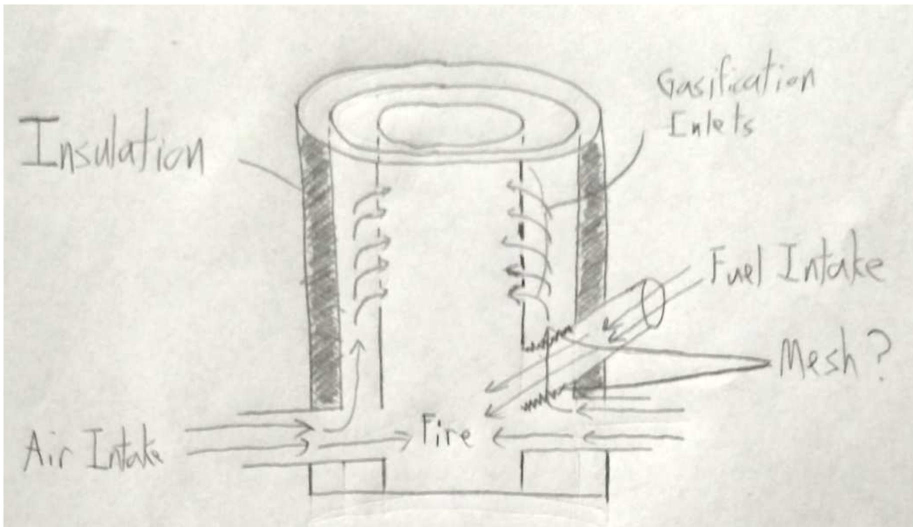

FIGURE 13: GASIFICATION WITH RADIAL INLETS

The second method that was chosen involved a pipe that was positioned to run through the center of the bottom of the stove to the top. (Figure 14: Gasification with Tube) This method provided the best means of performing controlled tests.

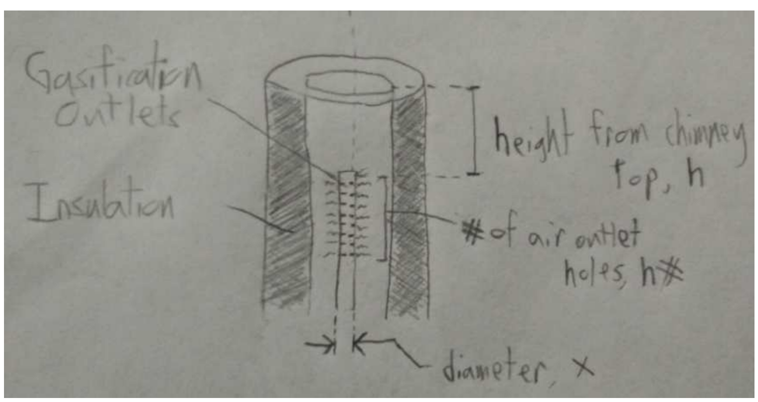

FIGURE 14: GASIFICATION WITH TUBE

5.4.3 Detailed Solution Development

The gasification tube that was chosen consisted of 27 holes drilled through a stainless-steel tube. This provided air from below the stove and channeled it into the burn chamber at an adjustable distance above the fire. The holes were arranged in groups of four that were positioned 90 degrees apart. Also, the holes were designed to be covered up to allow for a variable amount of airflow. A larger piece of pipe was used to cover the holes by acting as a sleeve. (Figure 15) The sleeve was held in place by a hose clamp secured to the gasification pipe. This provided the team with the opportunity to test variable flow rates.

FIGURE 15: GASIFICATION TUBE WITH SLEEVE

Another hole was drilled in the burn chamber grate to enable the gasification pipe to run through the center of the stove. The gasification pipe was secured by two pipe supports. (Figure 16) Lines were engraved on the gasification pipe to indicate different heights.

FIGURE 16: GASIFICATION TUBE SUPPORT

To test the gasification concepts, last year's stove was also modified. The previous team had focused on internal geometry and chimney height ratios which provided a foundation for gasification testing. From this year's internal geometry test, it was discovered that an air inlet to outlet area ratio of 1:1.8 was optimum. As a result, the stove was changed to a 4" inlet and 6" outlet to come as close as possible to the ideal ratio. The chosen gasification stove features were also installed. Due to the corrosion and embrittlement of last year's carbon steel chimney, this year's team upgraded to a stainless-steel burn chamber. (Figure 17) This provided greater corrosion resistance at hot temperatures. The perlite insulation from last year's stove was also reinstalled to ensure adequate heat retention.

FIGURE 17: STAINLESS STEEL BURN CHAMBER INSTALLMENT

5.4.4 Documentation of Embodiment

To better understand the design of the completed rocket stove, a CAD drawing was generated along with the bill of materials used in construction. The final assembly and CAD section view of the rocket stove can be seen in Figure 18. For a complete exploded view, along with part locations and a bill of materials, see Appendix N.

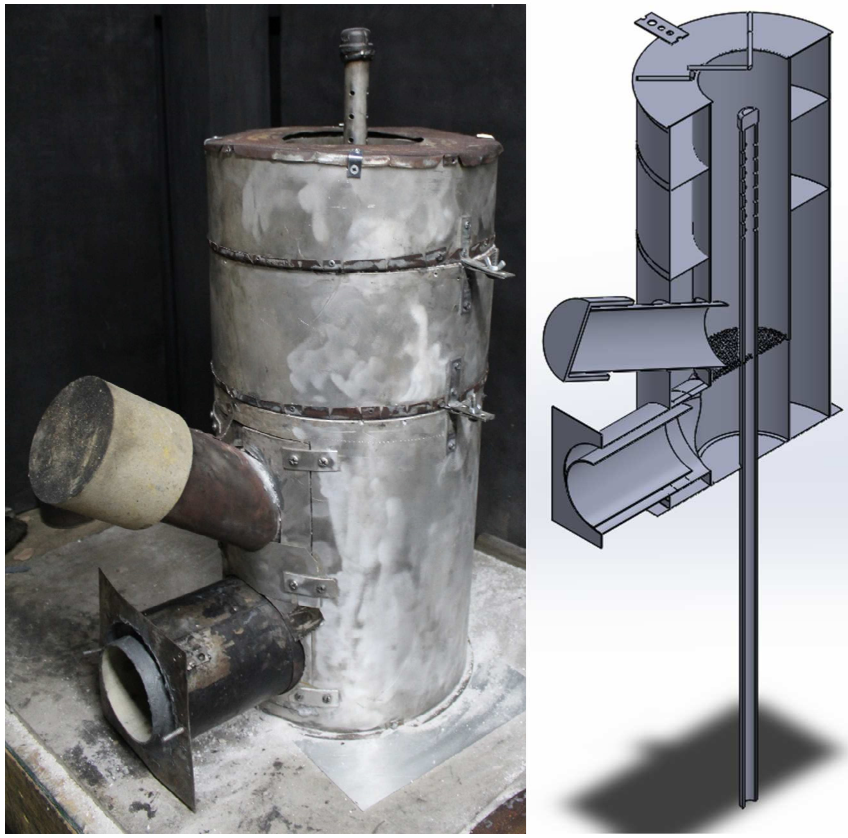

FIGURE 18: FINAL ASSEMBLY (LEFT) CAD SECTION VIEW (RIGHT)

5.4.5 Discussion of Embodiment

Updating the stove began with dissembling the top stove sections to install new components. First, the old pearlite insulation was removed to be later replaced after the installment of the burn chamber. The burn chamber was removed due to corrosion damage and embrittlement and replaced with a more thermally resistant stainless steel. The burn chamber pipe was secured via tack welds and sealed using JB weld. To streamline the fabrication process, the burn chamber was plasma cut to fit around the stove air intake and feeding tube rather than attempting to cut multiple exact holes. (Figure 17)

Changing the 6” air intake to the 4” diameter required a plasma cut disk to seal the gap between the two pipes. To install the gasification pipe, the burn chamber grate needed to be cut. Due to accessibility, it was roughly hand cut via wire cutters to the size of the gasification tube diameter. This resulted in the grate not completely catching the burnt fuel fragments as intended, but this proved to have a negligible effect on the stove performance. To secure the gasification pipe, the team decided on an external method using a clamp system seen in Figure 16. This provided an easily adjustable method for testing the gasification at high, medium, and low heights. The stove sections were connected to each other via L brackets that can been seen in Figure 19. Each section had a partitioning cover that served as a burn chamber centering mechanism and insulation container. An end cap was found to cover the fuel intake pipe to prevent any unwanted air entering the stove except through the air intake pipe. The completed test stove is seen in Figure 18.

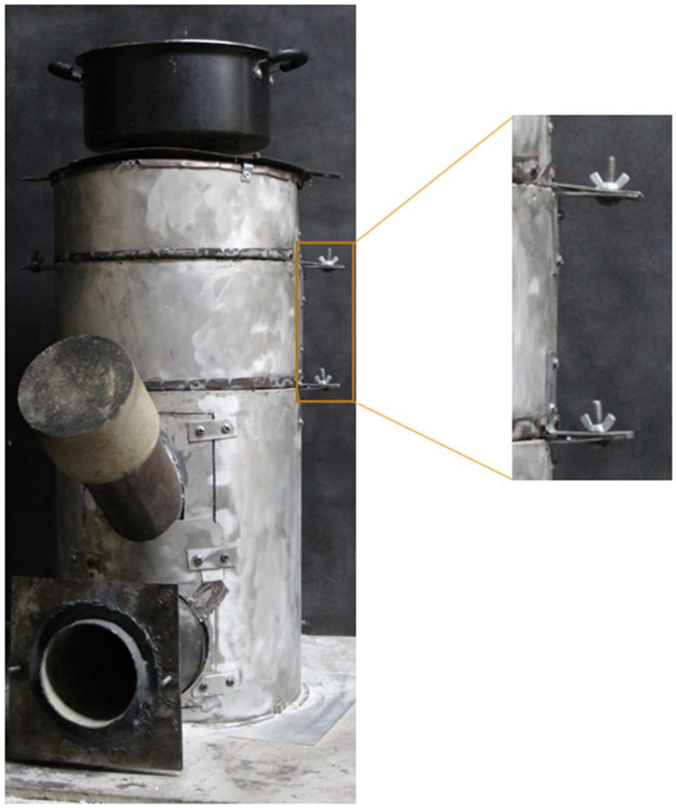

FIGURE 19: L BRACKET SECURING METHOD

5.4.6 Assessment of Embodiment

The rebuilding process of the stove was straightforward at first but grew more complex and comprehensive as the building process progressed. The remodeling process originally began with just a few minor changes such as replacing the inner burn chamber with stainless steel and changing the air inlet diameter. However, once the construction process began, the number of necessary modifications increased. One piece of additional work that was essential to replacing both the air inlet and burn chamber was the process of sealing the cracks created by these new design features. JB Weld, Rutland Cement, and tack welds were used to secure and seal the two main design upgrades. Also, the sheet metal sections that contained all the insulation had to be enlarged to fit the new burn chamber. To abide by the ideal outlet diameter to chimney height ratio the chimney height also had to be reduced. This was accomplished by cutting the external pipe down and reattaching the sheet metal top. The design changes that were required to produce an optimal performing stove were not apparent at first but became clearly visible as time progressed. The final stove design incorporates all the essential modifications. The gasification pipe system also had several modifications that were necessary for completion. A design change that was not very apparent at first involved the clamp that would hold the sleeve in place over the gasification holes. A hose clamp was found to be the best method for securing the sleeve after several tests. Also, multiple sleeves were cut to ensure adequate covering of the various holes. Overall, the original design of the stove and gasification system were simple and well thought out, but they lacked some key components which were added in later.

5.4.7 Assessment and Validation of Concept

Testing the stove with the gasification pipe installed provided surprising results in regard to performance and efficiency. The specific results of these tests are discussed in detail in Section 6 of the report. The main results of the gasification tests that were completed showed that a large amount of noise existed in the tests. Also, the initial tests showed that gasification did not significantly improve the stove's performance or efficiency. These results were puzzling to consider. As a result, the team decided to rethink the testing strategy that was used and discovered that one potential solution to these problems would be to refine the testing process to provide a clearer picture of the effects of gasification. More testing was completed with this mindset while using the same materials and components. This allowed the phenomena of gasification to be more closely examined which produced better results. A potential solution that the team implemented involved changing the response variable from primarily performance to efficiency. The specific response variable that was used involved measuring the air quality of the stove. By analyzing the amount of carbon monoxide contained in the smoke from the stove, a better glimpse into the effects gasification has on efficiency was gained. Overall, the testing that was performed at first enabled the team to revise and achieve better test results as time progressed.

5.4.8 Revision of Design Concept Based on Assessment and Validation

The main revisions that were briefly discussed in the previous section involved conducting a series of refined gasification tests. Once these tests were conducted using the same setup, the effect that gasification has on both efficiency and performance was clearly seen. A more detailed explanation of the results can be seen in Section 7 of the report. The second main revision that was implemented involved performing tests that measured the air quality of the stove. To effectively measure the air quality, a flue was constructed out of stovepipe. The flue was constructed to cool down the heated smoke vapors as well as collect carbon monoxide. The design of the flue can be seen in Figure 20. The diameter of the stovepipe was 6 inches, and the pipe sections were connected using aluminum tape that also sealed the stovepipe. The flue was held above the stove with metal pipe hangers that were connected to the ceiling of the test shed. A hole was drilled toward the end of flue to enable the carbon monoxide probe to be inserted.

FIGURE 20: FLUE DESIGN

Once construction was complete, air quality tests were performed by measuring the carbon monoxide content found in the flue. These air quality tests not only examined the effects of gasification, but they also analyzed the carbon monoxide content of a three-stone fire and an optimal performing rocket stove without gasification. The reason for expanding the testing base was to provide a better perspective on the effect that gasification has on the combustion process. Overall, the two main revisions that were completed provided higher quality results effectively addressing the shortcomings found in the previous tests.

5.5 Thermoelectric Power Generation with TEGs

5.5.1 Introduction

One goal of the project was to convert thermal energy produced by the stove into electrical energy that could be used to charge a handheld device such as a cell phone. This year's team built on the progress from the 2015-16 Disaster Relief team by investigating thermoelectric generators (TEG) in more detail.

5.5.2 Design Solution

The team continued pursuing TEGs for power generation for a few reasons. First, TEG's are like Peltiers, however, a TEG produces a voltage when there is a temperature gradient between the hot and cold side of the TEG. On the other hand, a Peltier produces a temperature difference between its two sides when a voltage is run through the device. Using TEG's only requires converting thermal energy to electrical energy, thus leaving out many steps that other methods would require. Next, TEGs have no moving parts, which many of the other methods do. No moving parts decreases the likelihood of something breaking, and in a disaster situation the last thing a user wants to do is fix a bunch of broken parts. Finally, a TEG is very simple to implement. All that is needed is a source of heat for the hot side of the TEG and a way to cool off the cold side of the TEG.

5.5.3 Detailed Solution Development

With the continued testing of various TEG's, the team set out to further research different types. Considerable research was done into existing systems currently being used on the market. (Section 2.6.4)

5.5.4 Discussion of Embodiment Process

With quality thermoelectric generators being expensive, the team initially bought some mid power and mid efficiency the TEGs to do initial testing. The testing method for testing setup for the mid- range TEGs can be seen in Figure 21 and Figure 22. After testing with the low and midrange quality thermoelectric generators, the team then purchased the IPowerTower™. The IPowerTower™ was purchased for a few reasons that will be discussed in section 5.6.4. The specs for the two TEG's purchased and IPowerTower™ can be seen in Appendix Q and Appendix R.

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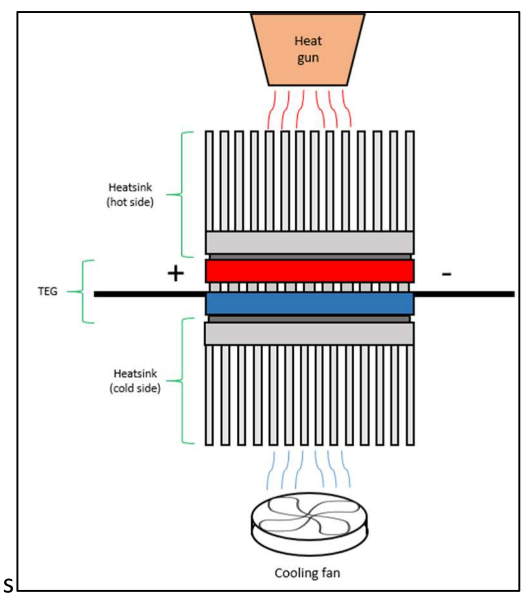

FIGURE 21: TEG CONCEPT

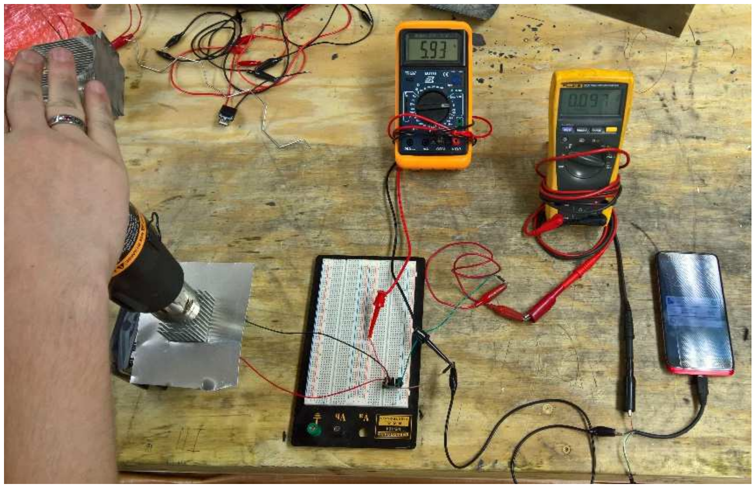

FIGURE 22: TEG TESTING

5.5.5 Assessment of Embodiment

An issue that the team came upon when testing the thermoelectric generators was that TEGs are very sensitive to extreme temperatures. Low quality thermoelectric generators would break when exposed to high temperatures, whereas the midrange TEGs needed more heat than the heat gun used in lab testing could provide. The testing of the IPowerTower™ proved to be more effective as the hot side temperature was a controlled burn from a Sterno™ Can. Figure 23 shows the testing done on the IPowerTower™ using a Sterno Can.

FIGURE 23: IPOWERTOWER™ SETUP

5.5.6 Assessment and Validation of Concept

The mid-range TEG successfully produced 5 Volts and charged a phone, but at a very slow rate of charge. The IPowerTower™, on the other hand, produced a constant 2 Watts of powers. The concept of electrical generation was proved in both tests, however, only the

IPowerTower™ was able to produce enough electricity to charge a phone at a reasonable rate. The team learned more about how the temperature difference on the TEGs makes a huge difference. The downside is that the team did have to purchase an already existing system. However, the team reverse engineered the system to fit the specific needs of a disaster relief rocket stove.

5.5.7 Revision of Design Concept Based on Assessment and Validation

When the initial testing, using air cooling, proved to work but not near what was desired, the team moved to the IPowerTower™. The IPowerTower™, on the other hand, did produced a constant rate of charge that met the goals. The unit itself is large, quite expensive, and does require a redesign. The team chose the IPowerTower™ as it was an already tested device that provided electricity with just a Sterno Can for a heat source. Using this product would allow the team to reverse engineer and enhance the unit to fit the needs of a rocket stove. This would allow for a better system that has features crucial to the stove's needs with much lower cost. The team also found from testing and talking with TECTEG that the IPowerTower™ could produce more power with greater temperature. The Sterno Cans used do not get close to the TEG's 300°C maximum temperature. More power would be produced if the hot side temperature was brought closer to the maximum.

5.6 Regulating Temperature on Hot Side of TEG

5.6.1 Introduction

To achieve the best results using a TEG, the hot side of the TEG needs to be kept as hot as possible without overheating the device. A TEG's electricity generation increases proportionally to the temperature difference between the hot and cold sides. Therefore, to generate the most energy using the TEG, the team sought to find a way to keep the hot side of the TEG just below the maximum rated temperature for the TEG.

5.6.2 Design Solution

The team thought of a few ways to regulate the hot side temperature of the TEG. Last year's team attempted to use a power stand. A power stand was a piece of aluminum that was placed in the fire and conducted heat to the TEG. It regulated the heat conducted by using a calculated cross sectional area to reduce the effective conduction area. This worked for preliminary testing but could not adjust to regulate heat from fires of different temperatures. This year's team chose to investigate a dynamic system that could restrict heat input to the TEG to a constant maximum temperature no matter the temperature of the fire. With the use of the IPowerTower™, the team decided to peruse regulating the temperature of air flowing through a heatsink attached to the TEGs.

5.6.3 Detailed Solution Development

The team developed the solution by ideating in terms of the necessary functions and limits that the temperature regulation device must have. The device must be able to limit the temperature that the hot side of the TEG reaches to 300°C, must be cheap to manufacture, and must be sustainable. After significant testing (See Section 6.2), the team decided to use a bimetallic coil as a sensor to turn a flap that would limit airflow to the TEG's. A bimetallic coil is simply two strips of metal joined together that have different coefficients of thermal expansion (called a "bimetallic strip") plastically deformed into a helical shape. The bimetallic coil used in testing can be seen below in Figure 24.

FIGURE 24: BIMETALLIC COIL

Two of these coils were used in the final solution to produce the necessary torque to drive a set of gears and the subsequent flap.

5.6.4 Discussion of Embodiment Process

After much brainstorming and research, the team set out to build a prototype, seen in Figure 25, of what would be called the TERSEC (TEmperature Regulation System for Electrical Components). As seen in Figure 26, the TERSEC is an air flow temperature regulatory system. It works by using bimetallic coils, that when heated will rotate causing the flap to block airflow to the TEGs. (Figure 27) As the bimetallic coils cool they will rotate back thus allowing hot air to the TEGs. They will eventually reach a steady state point where they maintain a constant temperature.

FIGURE 25: TERSEC BUILDING PROCESS

FIGURE 26: TERSEC TESTING

FIGURE 27: BIMETALLIC COILS IN TERSEC

5.6.5 Assessment of Embodiment

The TERSEC was tested and proved to work well. A few different changes were made between the first and second prototype models. The second prototype used JB Weld for higher temperature requirements, two bimetallic coils, and a hood to gather more hot air from the fire. This allowed the second prototype to work much better than expected. The second prototype worked so well that it limited the temperature too much resulting in a lack of heat. This ended up limiting the power output from the TEGs.

5.6.6 Assessment and Validation of Concept

The TERSEC proved to be a reliable solution for temperature regulation. It reached a steady state temperature that was safe for the TEGs to use. Figure 28: TERSEC Temperature Results shows the results from testing the TERSEC with a rocket stove. The TERSEC successfully regulated the incoming air to a safe temperature. After a few minutes, the stove and TERSEC were up to operating temperature. The temperature graph shows that the TERSEC reached a steady state temperature of 190-200°C. This temperature was a bit low as the ideal temperature is just below 300°C. A safety factor must be added when considering the maximum temperature but the TERSEC does need modification to allow for higher temperatures.

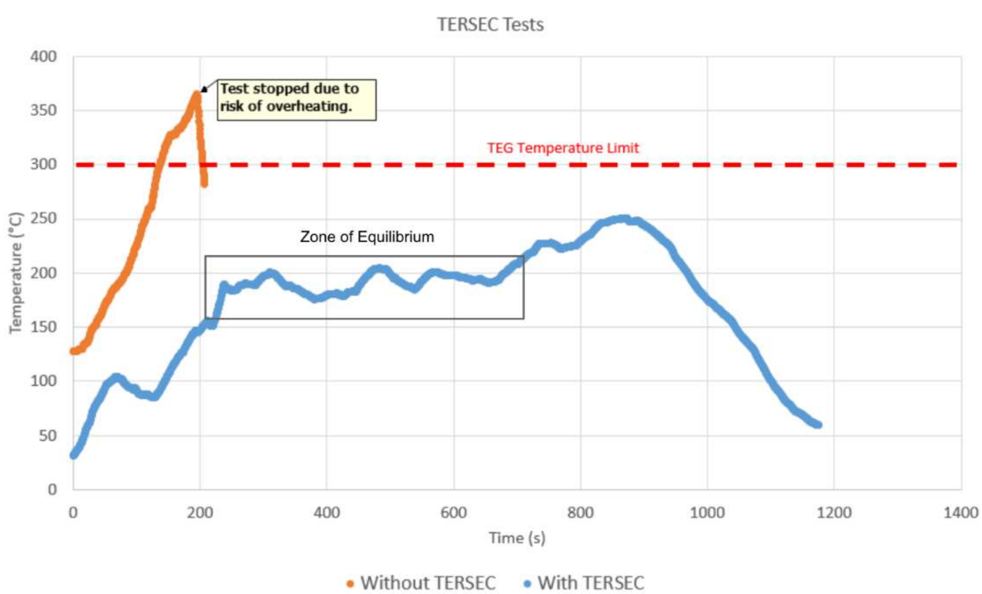

FIGURE 28: TERSEC TEMPERATURE RESULTS

5.7 Regulating Temperature on Cold Side of TEG

5.7.1 Introduction

To achieve the best results using a TEG, the cold side of the TEG needs to be kept as cool as possible. TEGs generate more electricity when the temperature difference between the hot and cold sides is maximized. Therefore, to generate the most energy using the thermoelectric generator, the team sought to find a method of obtaining cooler temperatures on the cold side of the TEG than convection to free air could achieve.

5.7.2 Design Solution

The team thought of several ways to cool the cold side of the thermal electric generator. The two main ways that the team investigated were using either air cooling or water cooling. Several heat sinks were tested and after many tests revealed that conventional air convection was not enough a fan was added to assist in the cooling process, as prototyped in Figure 29.

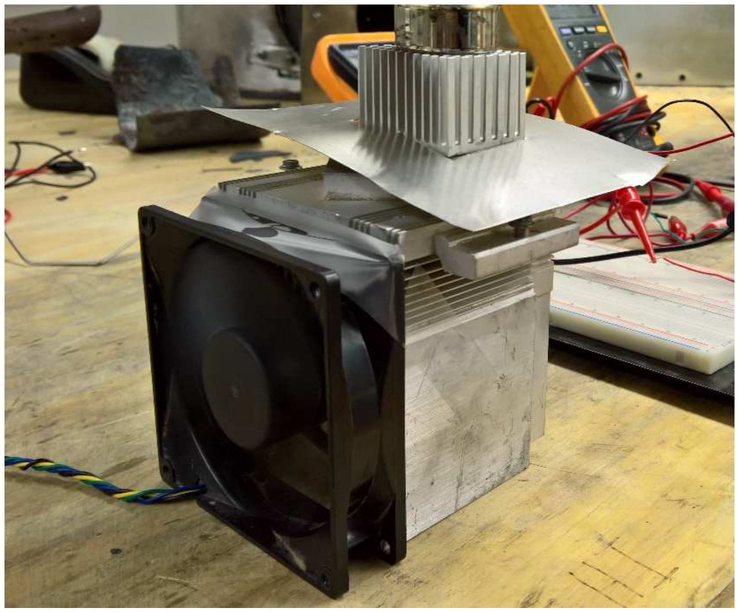

FIGURE 29: FAN COOLED HEATSINK

5.7.3 Detailed Solution Development

After further testing using heatsinks and fans showed that a more effective solution was needed, the team investigated liquid cooling. There were many resources where people used a pan with water or even complex pumping systems to cool the TEGs. [25,26] The team researched further and found TEGTEC who already made various systems that incorporated water cooling of TEGs. One of the systems they make is the IPowerTower™ which is a small unit designed to cool TEGs through water cooling.

5.7.4 Embodiment of Solution

The team decided to purchase the IPowerTower™ as it was a tested design that worked and had other features the team could use. During testing on previous cooling systems, the 2015-2016 Disaster Relief team found that one problem with using water to cool the TEGs is

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[25] "Solar Hot Water Heater & Power Generators." *EspressoMilkCooler.com*, Thermoelectric General Technology, 29 Oct. 2015. Available: espressomilkcooler.com/solar-hot-water-heater-power-generators/. Accessed Apr. 2017.
[26] "Water Cooled Thermoelectric Generator TEG Power - Devil Watt 100 Watt Wood Stove." *Devil Watt 100 Watt Thermoelectric Generator*, TEGMART, 27 Feb. 2014. Available: www.tegmart.com/thermoelectric-generator-products/devil-watt-teg-power-100-watt-water-cooled-wood-burning-stove-thermoelectric-generator/. Accessed Feb. 2017.

the water starting to boil. When this occurs and the water evaporates, water must be manually added to the reservoir. To help prevent this, the IPowerTower™ has fins on the water tank that help dissipate heat, keeping the water from boiling. The IPowerTower™ also has a valve on the water tank that allows the water to be drained and replaced when needed. The electrical subteam decided to reverse engineer the IPowerTower™. By taking a working product and figuring out why it works the team was able to save a large amount of time. The main part that was reengineered was the circuitry. The team designed a circuit that would regulate the voltage and charge a phone. The team also designed the circuit with LED lights that could be used. This circuit is illustrated in Appendix S. The specs for the IPowerTower™ can be seen in Appendix R.

5.7.5 Assessment and Validation of Concept

The IPowerTower™ has proven to be a great unit for providing electricity while keeping the TEG's cool. Through various tests using a Sterno Can, the IPowerTower™ was able to charge a cell phone at a constant rate of 2 Watts. Also, the water temperature never come close to boiling which proved the IPowerTower™ design worked. The IPowerTower™ proved to be the best solution to cooling the TEG's. It kept the TEG's at a low enough temperature to produce electricity and provided other features such as a way to heat water. The primary downside of the IPowerTower™ is its physical configuration and difficulty interacting with a rocket stove. This is a problem that next year's team can look into fixing by designing their own version of the IPowerTower™ that will be easily integrated with the stove.

FIGURE 30: TERSEC TESTING

5.8 In-Ground Stove

5.8.1 Introduction

One of the Field Expediency subteam's goals was to investigate a very basic, simple, and field expedient stove type called the in-ground stove. The subteam set about to observe similarities in performance and functionality between the in-ground stove and a standard rocket stove. In disaster situations, the need for warmth and food exists. The in-ground stove is a method often used as it not only meets those needs, but it does so in a time efficient manner.

5.8.2 Design Solution

The team settled upon the concept of an in-ground stove to meet this need. This stove allows for easy customization of dimensions and requires virtually no building materials. The team approached the problem of optimizing the in-ground stove by building multiple versions of different sizes. Through building multiple stoves such as seen in Figure 31: Early Testing Apparatus, the team determined what components were essential for quick building of the in-ground stove.

Figure 31: Early Testing Apparatus

5.8.3 Detailed Solution Development

Initial tests had holes dug in the ground in a layout similar to the rocket stove, having air inlet and outlet holes. The in-ground stove is comprised of two holes dug into the ground in proximity to each other with a connecting hole acting as a tunnel between them. The dimensions are driven by research gathered from the stove team. The dimension ratios are 1:3 for the outlet to stack height and 1:1.5 for the inlet to outlet hole diameters. The subteam used these dimensions to embody the concept for testing.

5.8.4 Documentation of Embodiment

The in-ground stove testing procedure is shown below using dimensions based on the ratios previously described:

- Dig a hole approximately 6 inches in diameter and up to 22 inches deep. This hole serves as the fire chamber. Its depth is the stack height combined with the depth needed to add the connecting hole to the bottom.
- Dig a second hole of any diameter, usually between 8-12 inches and up to 24 inches deep, a distance of about 4”-8” away from the first hole.
- Dig a tunnel in the ground that connects the first two holes and has a diameter of about 4 inches.
- If possible, install a metal grate into the dirt just above the inlet connecting hole in the fire chamber.

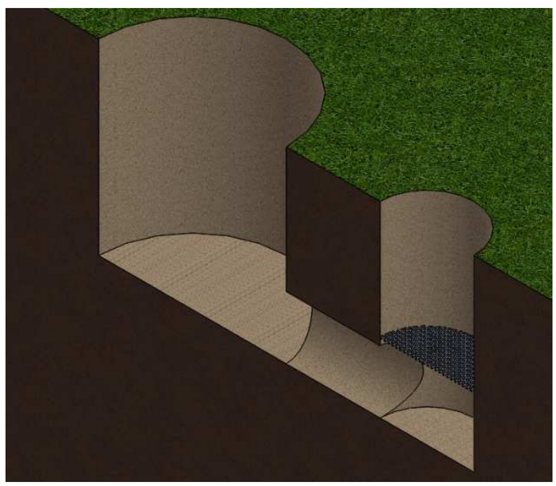

FIGURE 32: IN-GROUND STOVE RENDERING

- The burning process begins as any fire. Having fire starter, tinder, kindling, and larger fuel are optimal to start a fire. The fuel is inserted into the top of the stove. Having fire starter, tinder, and kindling initially inserted is best. Light the fire starter. Once kindling is burning, begin adding the larger fuel. Once fire has been started and fuel is lit, continue adding as needed.

5.8.5 Assessment and Validation of Concept

This process allowed for quick, low-cost building of an in-ground rocket stove. It took approximately 10 minutes to dig the holes and deploy the completed in-ground stove during testing trials. The tests were successful as the team was able to observe behavior consistent with the rocket stove model.

5.9 In-Ground Stove Support System (IGSSS)

5.9.1 Introduction

To create a stove that can be deployed to disaster situations and developing countries, rocket stove technology must be simplified to its most fundamental level. The Disaster Relief Solutions team sought to apply rocket stove design principles to situations with extremely limited resources by designing and testing a system that incorporated the primary design ratios of a rocket stove. The goal was that this simple stove could be built by an individual with minimal technical knowledge and only basic tools.

5.9.2 Design Solution

To improve upon the in-ground stove, one solution that seemed feasible and exhibited rocket stove style performance was a pre-fabricated pipe with a pre-cut air inlet hole and a pre-installed grate. This solution addressed the problems of maintaining constant, optimal dimensions, reducing the amount of moisture being released into the fire through the dirt, and low reusability due to dirt walls crumbling. The team chose to investigate the best construction and deployment methods of this pipe and grate system, called the In-Ground Stove Support System (IGSSS).

5.9.3 Detailed Solution Development

To take this concept of a pre-fabricated pipe from an idea to a solution, the team looked at what components needed to be incorporated into the pipe. To achieve the fundamentals of rocket stove performance, the team concluded that an air inlet hole and wood support grate were the only components needed. Additionally, multiple methods were considered for the means of affixing the grate inside the pipe. Welding was the natural option, but the team decided to use metal screws as supports beneath the grate and a press fit tolerance in order to simulate field solutions. The dimensions for the system were determined by the ideal ratios that the team determined from the stove DOEs. A 4” inlet diameter and 6” outlet diameter ratio was chosen for the IGSSS test stove.

5.9.4 Embodiment of Solution

The embodiment of the solution designed on paper started with finding a pipe with the correct diameter of 6 in. From there the team looked for a grate material that would both be sturdy for long use and easy to cut to the 6 in diameter dimension for the pipe used. The team used a jig saw to cut the inlet hole out of the pipe and press fit the grate into the pipe. Another option for the body of the support system was a fire extinguisher cut to the correct dimensions.

5.9.5 Documentation of Embodiment

In-Ground Stove Support System build procedure:

1. Find a pipe which can accommodate a 1:3 outlet diameter to chimney height ratio. Using example dimensions, have an outlet dimension of a roughly 6-inch inner diameter

and approximately 22 inches long. This pipe length accommodates for the hole which must be cut into the bottom of the pipe for the inlet hole.

2. Find material suitable for a grate. A medium size grate with approximately ¼ to ½ inch gaps and preferably stainless steel if it can be found. Otherwise other materials are suitable but will not last as long. Aluminum will melt after the first use and carbon steel will oxidize and corrode due to high temperature exposure.

3. The grate should be cut to the same area as the outlet of the pipe. For a 6-inch diameter pipe that would be approximately 28.27 in^2.

4. Cut a hole into the side of the pipe that has an area of approximately 12.57 in^2 for an approximate 4-inch diameter inlet hole as shown in Figure 33. If a 6-inch diameter pipe is not found cut a hole into the pipe that has a ratio of 1:1.5. For every 1 inch of inlet diameter there is an inch and a half of outlet diameter.

FIGURE 33: 4" INLET IN IGSSS

5. Cut 1/8-inch round bar into two pieces about the length of the diameter of the pipe. The bar can be made from a range of materials from raw drawn steel to stainless steel. An alternative option to the round bar would be bolts placed into the sides of the pipe extending beneath the grate.

6. Drill four holes into the pipe perpendicular to the inlet hole, two on each side of the top of the inlet hole. These holes need to be the same diameter as the diameter of your round bar.

7. Install the grate by inserting it into the pipe and have the round bar slide through it from one side of the pipe to the other to hold it in place.

8. If possible, weld the round bar components into place once the grate is installed. If stainless steel wire is used twist the end of the wire and flatten it to the pipe. The final product can be seen in Figure 34.

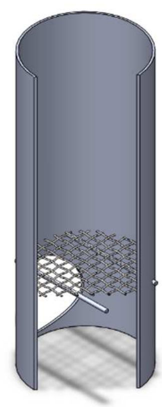

FIGURE 34: SECTION VIEW OF IGSSS

Discussion of embodiment process: This system took shape by using a variety of processes. The inlet hole was created by using a jigsaw to cut the hole into the pipe. The grate used was scrap metal and was cut to rough dimensions using metal shears. The fire extinguishers also proved to be very useful bodies for the support system. (Figure 35) A band saw was used to cut the top off the extinguisher after all pressure had been expunged, but a simple hand saw could be used in situations with limited tool availability. The holes for the round bar were created using a drill. The grate was installed by pushing it down into the pipe and sliding the round bar through it to secure it into place. The round bar was then welded into place in the pipe to complete the embodiment of the system. The most difficult part of the embodiment process was installing the grate because the inlet hole was not the quite the right dimension.

Figure 35: Fire Extinguisher IGSSS (Left) Installed IGSSS (Right)

Assessment of embodiment: The actual embodiment of the design turned out to be like the drawing on paper. The embodiment of a deployable in-ground stove support system design was very close to what the team had envisioned from the beginning. It matters to the team because a physical specimen can be given to disaster relief companies for use directly in the field. The IGSSS is an effective tool that works towards feasible, simple, life-saving solutions for nearly any disaster or resource-deprived situation.

Figure 36: IGSSS in Use

5.9.6 Assessment and Validation of Concept

The in-ground stove support system allowed for quick building of an in-ground rocket stove. It took approximately 10 minutes to dig the holes and deploy the completed in-ground stove support system during testing trials. To build the pipe version of the in-ground stove support system, approximately 20 minutes are required, versus 25 to 30 minutes to construct the fire extinguisher version. Tests were successful for these stoves and exhibited rocket stove performance characteristics more vividly than the simple in-ground stoves. The IGSSS was an effective way to ensure accurate dimensions for the in-ground stove while still using minimal materials.

6 Implementation of Designs and Testing Procedures

6.1 Stove Team

6.1.1 Internal Geometry

6.1.1.1 Introduction

The rocket stove internal geometry was tested to optimize the Venturi effect. This effect describes the phenomena when a fluid moving at high velocity creates a region of low pressure around it and draws induces movement in the surrounding fluid. In a rocket stove, this is evidenced by the superheated air rising from the burn chamber up through the chimney of the stove and creating a low-pressure void below the burn chamber that draws air through the inlet. Last year's team had conducted a similar experiment but had instead used restrictor plates rather than changing the dimensions of the entire air inlet and outlet. At the conclusion of last year's tests, the team recognized that the restrictor plates may have influenced the consistency of air flow through the stove. This year, the team chose to optimize each stove's performance and eliminate every source of error possible by fabricating each stove with a specific inlet to outlet ratio. (Section 5.2)

6.1.1.2 Testing Goal

The goal of this Design of Experiments (DOE) was to determine the optimal inlet area to outlet area ratio for a rocket stove. Furthermore, the tests would prove whether the restrictor plates used last year were sufficient in lieu of altering the internal geometry.

6.1.1.3 Test Design

To test a variety of internal geometry ratios with a DOE, the team designed a test plan with two factors, chimney diameter and inlet diameter, and multiple levels for each. As seen in Table 5, testing three replicates of every combination of levels resulted in 18 total tests. The response variable used in the DOE consisted of temperature ramp rate (°C/s). The device used to collect the ramp rate was a thermocouple connected to a NI 9219 Data Acquisition Unit connected to a LabVIEW Virtual Instrument program. The J thermocouple was placed in a pot with 1 liter of water that was placed on top of the stove while a K thermocouple was placed below the pot to determine the fire temperature.

Factors	Levels		
Chimney Diameter (inches)	3	4	6
Inlet Diameter (Inches)	3	4	

Factors	Outlet Area	X	Inlet Area	X	Replicates	=	Total # of Samples
Levels	3	X	2	X	3	=	**18**

Table 5: Internal Geometry Factors, Levels, and Total Samples

6.1.1.4 Testing Procedure

The testing procedure is included in Appendix K. It includes a warmup phase to ensure that the stove body temperature has reached steady state, steps for setup of the DAQ and water pot, and reminders for data storage. The team followed this process very closely for each test as a means of eliminating noise from the DOE results.

6.1.1.5 Challenges and Resolutions

The main challenge during the internal geometry DOE was comparing the different stoves as they all had different burn rates. The time between each fuel feed was investigated as a potential source of error since each stove should have optimal performance at a specific rate of feeding. For instance, a high-performance rocket stove would appear to perform very badly during testing if it were tested with a long time interval between fuel feeds and starved for fuel. Thus, preliminary testing was performed to find the optimal time between feed for each stove. The process began by feeding the fire one piece of wood at certain time intervals. By observational study, if the fire appeared to be starved then the time interval between each piece of wood was decreased. When a rate was found that overloaded the fire, the interval was increased. At this point in the process, preliminary tests were conducted by heating 1 liter of water on the stove and measuring the ramp rate of water temperature for three different feed intervals. These intervals were the suspected optimal time interval, and then two intervals ±5 seconds. This was designed to ensure that the optimal feed delay was found. Appendix G displays the results of feeding time interval tests.

This scaling included the different height of the chimneys. The chimney height of each of the rocket stoves depends on chimney diameter to eliminate this dimension as a factor. Based on experimentation from last year, the optimal ratio of outlet diameter to chimney height is 1:3.5. This ratio was used to eliminate this factor. For example, a chimney diameter of 3” has a 10.5” chimney height.

6.1.1.6 Assessment of Tests

The internal geometry design of experiments performed excellently. After analyzing the data in Minitab, the highest obtained P-value was 0.001. These low P-values confirm that significant data resulted from the DOE. One hypothesis for this is because the data was collected over such a wide range of levels and the procedure contained very few possible sources of error.

The determined optimal ratio agreed very closely with the data collected while using the restrictor plates but not exactly. Therefore, it was determined that the entire internal geometry of the stove is a significant variable.

6.1.2 Pot Accessories

6.1.2.1 Introduction

The pot accessories are simple components that surround the pot to increase heat transfer. Testing these components was conducted by finding the ramp rate of water temperature in the pot when using the different accessories, since this temperature change reflects the increase or decrease in heat flux.

6.1.2.2 Testing Goal

The non-DOE pot skirt testing gave comprehensible and simple results that portrayed the desired information. Since this testing was not the focus of the project, a full-DOE was not run on these components. The goal of the testing was to confirm that a pot skirt did improve heat transfer into the pot. Additionally, the pot stands (i.e. cross-brace stand and heat exchangers) also were tested to see if they improved heat transfer to the pot.

6.1.2.3 Test Design

The test design was very simple. Since the pot accessories were not affected by an actual rocket stove, only a heat source was needed. The propane torch with a chimney was ideal for getting a constant flame. The various accessories were placed on top of the chimney and results were measured using a J-type thermocouple connected to a National Instruments Data Acquisition which was connected to a simple LabVIEW program. The response variable for this experiment was the ramp rate of water temperature. The various configurations included one of the two pot stands and tests with and without the pot skirt.

Factors	**Levels**	
Flux Ring	No Flux Ring	Flux Ring
Pot Enclosure	No Pot Enclosure	Pot Enclosure

Factors	Flux Ring	X	Pot Enclosure	X	Replicates	=	**Total # of Samples**
Levels	2	X	2	X	3	=	**12**

TABLE 6: POT ACCESSORIES FACTORS, LEVELS, AND TOTAL SAMPLES

6.1.2.4 Testing Procedure

1. Turn on propane torch
2. Fill pot up with 1L of water
3. Place pot accessories on stove for specific test.
4. Place pot on stove with thermocouple in water
5. Start LabVIEW program and run test for 5 minutes
6. Stop test and save data

6.1.2.5 Assessment of Test

Overall the tests were very beneficial and significant. Even though a confidence level was not assessed on this data, the precise groupings for the various replicates proved that the test had significance. Additionally, the results provided the data that was desired.

6.1.2.6 Revision Recommendations

Since there were no major challenges in the experiment, no revision is recommended. However further testing could be conducted that demonstrates whether various sized diameter pot skirts increase or decrease the heat transfer to the pot.

6.1.3 Gasification

6.1.3.1 Introduction

Optimizing the fire triangle was one of the main reasons the team conducted these experiments. Determining the proper amount and location of oxygen that a fire should receive was the objective for the gasification design of experiment. The team was also planning to observe the secondary burn phenomenon, known as gasification, during this experimentation process. A secondary burn, in previous preliminary tests, appeared to reduce emissions and improve fire efficiency.

6.1.3.2 Testing Goal

The primary objective for these experiments was to ascertain whether an additional supply of oxygen separate from the main air inlet could create a secondary burn. This process of inserting a stream of oxygen into the fire could improve performance and efficiency and reduce harmful pollutants, according to previous research. With this goal, the team constructed three design of experiments that would determine the impact that the gasification phenomenon has on a rocket stove fire.

6.1.3.3 Test Design

The first design of experiment used a response variable that consisted of temperature ramp rate (°C/s). This variable enabled the performance of the rocket stove to be analyzed along with the efficiency of the rocket stove. The efficiency of the stove was derived from the ramp rate of the stove and the mass of wood consumed by the fire.

The design for the setup used to collect the ramp rate was a thermocouple attached to an NI 9129 DAQ, which was connected to a computer running a LabVIEW program. A standardized pot of water was placed directly above the stove to gather the heat from the fire. The thermocouple was positioned in the pot of water to measure the temperature. This arrangement enabled the ramp rate of the stove to be collected effectively. The height and number of holes in the gasification pipe were the two factors in this DOE. Three levels existed for each of the factors that were tested. The team tested three different heights of the gasification tube to discern the optimal location of air injection. The amount of oxygen inserted was also tested by varying the flow rate. This was accomplished by drilling holes into the top of the pipe. An additional piece of pipe was placed over the gasification pipe to act as a sleeve, which enabled the airflow to be controlled. A detailed list of the various levels that were tested by varying these two factors can be found in Appendix H. Each level was tested with three replicates to obtain statistically significant results. A total of 27 tests were completed for this DOE, as seen in Table 7. Although the tests were connected smoothly, the results lacked statistical significance. (see section 7.2.1.4 for a detailed explanation)

Factors	**Levels**			
Tube Height (inches)	6	8	10	
Number of Holes	0 (Base)	4	16	28

Factors	Tube Height	X	Number of Holes	X	Replicates	=	**Total # of Samples**
Levels	3	X	3	X	3	=	**27**

Table 7: Gasification 1 - Factors, Levels, and Total Samples

To achieve better results, the team decided to conduct another DOE that was more refined by comparing only two factors. This DOE had the same response variable of water temperature ramp rate (°C/s). In this experiment, the efficiency of the stove was calculated by dividing the energy input to the water by the measured amount of fuel (wood energy) combusted during the test. The two factors that were tested consisted of the gasification pipe and the stove outlet, as seen in Table 8. The plan behind testing these two factors was to determine if the gasification phenomena improved fire performance and efficiency. Two levels were tested for each factor during this experiment while three replicates were taken for each level that was tested. The first pair of levels involved opening and closing the gasification pipe while the second pair dealt with opening and closing the stove outlet. These tests enabled the team to analyze the effects of gasification in a practical cooking environment as well determine the merits of gasification. Appendix I contains the complete list of the factors and levels that were tested.

The final DOE that was conducted after receiving surprising results from the first gasification DOE involved testing a different response variable. Air quality was tested in light of creating an efficient combustion process through gasification. The specific response variable for this test was determine the amount of carbon monoxide (PPM) contained in the smoke from the rocket stove. This response variable was quantified by using a CO monitor to determine the PPM. The CO monitor contained a hose that had a probe connected to the end of it. This probe was inserted near the end of the flue that was constructed above the rocket stove. (Figure 20: Flue Design) The CO content of the smoke was recorded from this monitor during each test. With this focus on emissions, the team gained another perspective on the effects of gasification. The stove air inlet and the gasification pipe were the two factors that were examined in this DOE. The levels consisted of opening and closing each of these factors while three replicates were taken for each level. A comparison test was also conducted alongside this DOE by measuring the carbon monoxide output of a three-stone fire. Determining the carbon monoxide output during low and high cooking conditions provided a baseline for the results of this DOE. Comparing the rocket stove with and without gasification to the three-stone fire gave valuable insight into the merits of gasification. A detailed list of the two levels and factors that were tested can be found in Appendix J.

Factors	**Levels**	
Chimney Outlet	Closed	Open
Gasification Tube	Closed	Open

Factors	Chimney Outlet	X	Gasification Tube	X	Replicates	=	**Total # of Samples**
Levels	2	X	2	X	3	=	**12**

TABLE 8: GASIFICATION 2 - FACTORS, LEVELS, AND TOTAL SAMPLES

6.1.3.4 Testing Procedure

The procedure for conducting a test for the first gasification DOE involved a significant amount of warm up time for the rocket stove. This startup time enabled the stove to reach a steady state in relation to heat retention. Once a specific amount of time passed, the testing process began. The process consisted of conducting a 5-minute water boil test. During this time, the pot was placed above the stove and the temperature was recorded with the main air inlet closed. The only oxygen inserted into the fire was from the gasification tube. After a test was complete, either the height or the airflow rate was changed according to the randomized procedure. (Appendix L) Only a certain amount of time could pass as the fire was fed to bring the stove back to steady state. This process of reheating and testing was repeated until three tests were completed. A cool down period was initiated until the fire was extinguished. The height of the tube or number of holes open was adjusted to the next test configuration in the DOE. The startup process was begun again and the process of collecting 3 more tests was continued. A total of 27 tests were completed in the first gasification DOE.

The second more refined gasification DOE began in a very similar fashion to the first gasification DOE. After a significant warmup time, the first 5-minute water boil test began. The pot was placed on the pot stand for the specific tests that required the stove outlet open. When the test configuration required a closed stove outlet, the pot stand was removed enabling the pot to be placed directly on the stove. This sealed the stove outlet. After each test, a specified amount of time was given that allowed the stove to heat back up to steady state. Three replicates for each factor/level combination were conducted sequentially. The process of reheating and testing was repeated until all 12 of the tests were completed. A detailed procedure for this DOE can be found in Appendix M.

The final air quality DOE contained a similar procedure to the previous DOEs. The testing sequence was begun with a specified amount of warmup time to allow the stove to approximately reach steady state. Once this was achieved, a 5-minute carbon monoxide test was started. After a test was completed, a warmup time was initiated to allow the stove to return to steady state. Three replicates were completed for each level. This process was continued until all the rocket stove replicates were completed. The second part of this experiment involved conducting similar CO measurement tests on a three-stone fire. These tests were performed in a similar manner as the previous air quality tests. Only two tests were conducted for this portion of the experiment. The first test was an example of a low temperature cooking application while the second involved a high temperature cooking application. Each test was measured in the same manner as the previous air quality DOE tests. The complete detailed procedure for all the air quality tests can be found in Appendix M.

6.1.3.5 Challenges During Testing

Several challenges were faced during the experimentation process. One of the main difficulties was standardizing the fuel feeding process. Stoking the fire and adding more fuel varied from test operator to operator. Also, the startup time to heat the stove to steady state proved at first to be inadequate. The environment in which the tests were conducted was another aspect that proved challenging to control. Some test days occurred during windy and cold conditions which seemed to affect burn rates and stove performance.

6.1.3.6 Resolutions to Challenges

To help standardize the fuel feeding process, one person was assigned the task of adding fuel throughout the test day. Also, the location of the fuel was standardized to obtain consistent flame distribution. An additional amount of startup time was added to help mitigate erroneous initial test results. Closing the test shed door was also a method of controlling the environment.

6.1.3.7 Assessment of Test

The overarching consensus from assessing the results of the tests was that a large amount of noise existed in the data of the first gasification DOE. The P-value for the number of holes' open was rather high, which indicated a lack of significance. The location of the gasification tube, on the other hand, proved to be more significant. During a troubleshooting session, the team decided to conduct the second more refined DOE that analyzed the gasification pipe and the stove outlet. Once this DOE was performed, the results significantly improved. The air quality DOE provided another perspective to the gasification process enabling the team to clearly view how gasification reduces harmful emissions such as CO.

6.1.3.8 Revision Recommendations

One significant revision involves conducting more air quality tests to determine the impact that gasification has on a rocket stove. In specific, analyzing the response variable of air quality in greater depth would provide excellent results. The DOEs that were performed exhibited good results, but the final air quality DOE could have been expanded to cover the gasification pipe locations and varying amounts of oxygen. The team discerned that a greater amount of useful data could be gleaned from concentrating on the response variable of air quality.

6.2 Electrical Team

6.2.1 Introduction

To generate electricity effectively from the TEGs, the team tested circuitry for voltage control to the USB port and temperature control for the heat delivered to the TEGs. Much of the testing was extensive yet preliminary, therefore experimentation and prototyping were the most common forms of testing.

6.2.2 Testing Goal

The overall testing goal was to determine a minimalistic and effective circuit design for voltage control to the USB port, and to determine a design for the temperature regulation on the hot side of the TEGs. For the electrical testing, the goal was to be able to charge a phone 20% in 1 hour. For temperature regulation, the goal was to develop a system that would regulate the temperature of the incoming air no matter the fire temperature and without any human input needed.

6.2.3 Test Design

With the electrical testing, two different tests were performed as two different voltage TEGs were tested. The first test was with lower voltage TEGs, less than 5 volts. This test involved the circuit set up seen in Figure 37. With lower voltage TEGs being used, a voltage booster was added to bring any voltage between 2.4 and 5 volts up to 5 volts. This allowed for the phone to be charged even with the TEGs were outputting less than 5 volts.

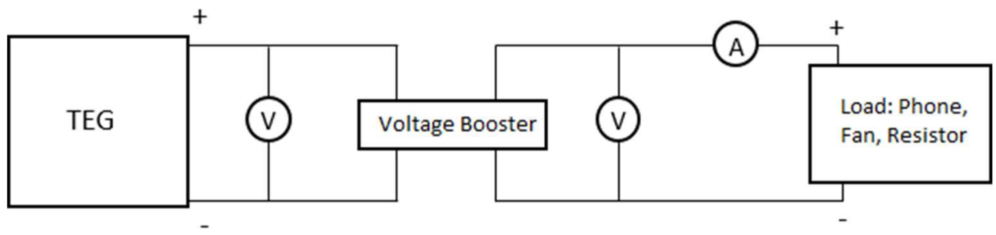

FIGURE 37: ELECTRICAL TESTING SETUP WITH VOLTAGE BOOSTER

For the second circuit, Figure 38, a voltage regulator was used. The higher voltage TEGs could output up to 20 volts. The voltage regulator would take any voltage above 5 volts and regulate it down to 5 volts.

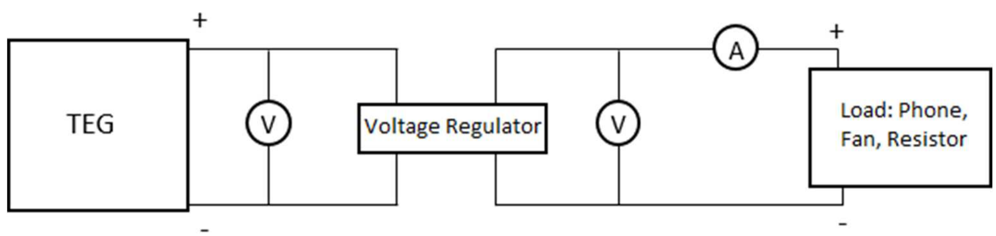

FIGURE 38: ELECTRICAL TESTING SETUP WITH VOLTAGE REGULATOR

For the temperature regulation tests, the team investigated the existing method of heat regulation from last year's testing. Last year's team used a heat energy regulation method, which worked only with a known fire maximum temperature. While working with the Stove team this year, the Electrical subteam realized that the fire temperatures vary so much that last year's solution would not work in some situations. If the fire passed the maximum temperature of the heat regulating system, the TEG would overheat and no longer work. This year's team decided to build a system that could not overheat. The system was to regulate the hot air from the fire and make sure that air above 300°C could not reach the TEGs.

6.2.4 Testing Procedure

For the electrical testing, the procedure was simple. In both circuit setups, the procedure was as follows:

1) Connect circuit as shown in Figure 37 and Figure 38
2) Apply heat source to TEGs
3) Measure the voltage and current output from system
4) Calculate power output from system

The temperature regulation testing procedure was as follows:

1) Attach TERSEC to IPowerTower™ (Figure 39)
2) Place IPowerTower™ and TERSEC directly above fire as shown in Figure 30
3) Attach thermocouple above air intake for IPowerTower™ (Figure 40)
4) Ensure that the flap is set to the open position allowing airflow
5) Attach the USB from the DAQ to the laptop
6) Open the program for recording temperature
7) Build a fire in stove and begin recording data on laptop using
8) If the temperature does not get above around 225°C, check to see if the TERSEC flap is completely closed. If it is closed, move the IPowerTower™ and TERSEC away from the fire and let the TERSEC cool down. Adjust the bimetallic coils where they will not close the flap at that low of a temperature.
9) Repeat step 8 as needed
10) Export data gathered on laptop for later use

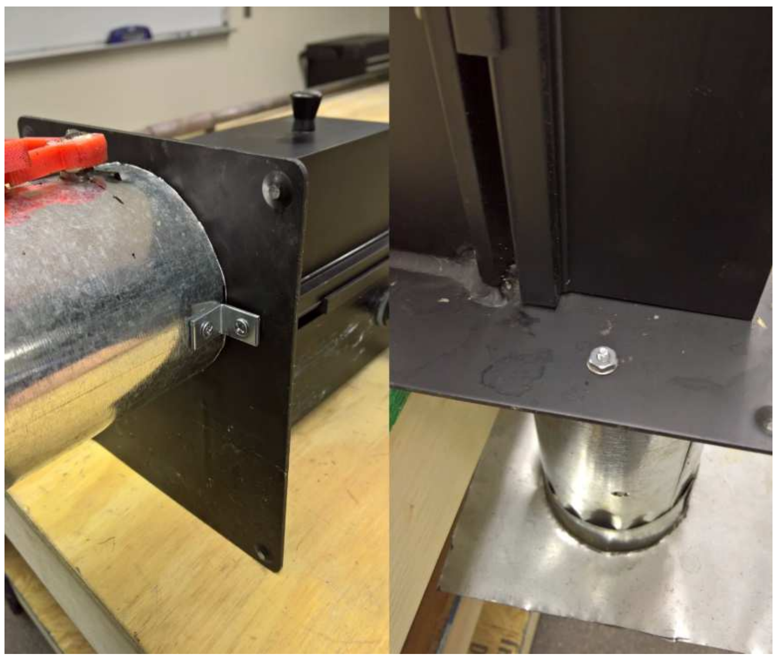

FIGURE 39: TERSEC ATTACHMENT TO IPOWERTOWER

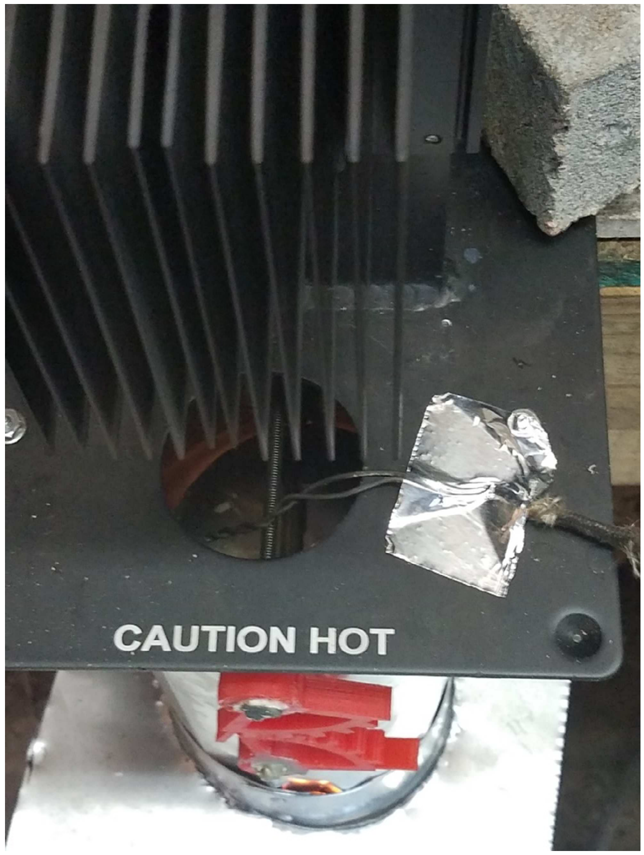

FIGURE 40: THERMOCOUPLE PLACEMENT

6.2.5 Challenges During Testing

One challenge during testing was the heating of the TEGs. Open flames were not allowed on campus, and therefore a permit would need to be obtained. To get around this, the team used a heat gun. However, the heat gun was not good at transferring heat to the TEG. Simply blowing hot air onto the hot side of the TEG was not enough. Another challenge with testing was the TERSEC would often have parts come loose with the application of heat.

6.2.6 Resolutions to Challenges

To resolve the application of heat to the hot side of the TEG, the Electrical subteam started to use a heatsink on the hot side of the TEG. By blowing air through the heatsink, more energy was transferred to the heatsink and therefore the TEG. This can be seen in Figure 21 and Figure 29. For the TERSEC parts coming loose, the team had to use a different adhesive. With some research, the team decided to use JB Weld as it has a very high maximum temperature. If there was more time, the team would have wanted to try using tack welds. This is a great thing for next year's team to pursue.

6.2.7 Assessment of Test

The tests performed were good tests that gathered the required data. The Electrical team would only recommend a couple of changes for the next team. First, now that the TERSEC works, it would be nice to have a temperature adjustment that would not require the system to cool down and something that would allow the changing in rotation of the bimetallic coils while testing was happening. For electrical testing, it would be good to add LED lights. The lights would use very little power, but it was a test which time did not allow.

6.3 Field Expediency

6.3.1 Introduction

To address the need for a better, simpler, more effective, and field expedient burning stove in disaster situations and developing countries, the team tested an in-ground version of the rocket stove. Taking things a step further, the team also designed and tested a model it labeled the In-Ground Stove Support System (IGSSS).

6.3.2 Testing Goal

The two key words that drove the team's testing were 'verification' and 'adaptability'. There were questions that the team wanted answered through this testing: Could an in-ground stove perform like a rocket stove with respect to parameters such as fire efficiency, fire strength, smoke content, and observable Venturi effect? Could the in-ground stove perform better hence providing a better and safer cooking option than a three-stone fire? Could the IGSSS prove adaptable and functional in a given disaster situation?

6.3.3 Test Design

It is important to point out that Field Expediency subteam did not conduct any DOEs. Thus, the testing done did not follow the procedure and breakdown typically attributed to a DOE. Nevertheless, the response variable amounted to being the Venturi effect which if observed to occur, would ratify one of the testing goals. The devices used for test conduction included shovels for hole-digging, a digital camera and a smartphone for data collection, and the IGSSS with an inlet-to-outlet ratio like that of the previously built rocket stove. During testing, data was collected in the form of pictures and videos that captured the essence of what the team had set out to verify.

6.3.4 Testing Procedure

The in-ground stove testing procedure is shown below:

- Dig a hole approximately 6 inches in diameter and up to 22 inches into the ground. This hole serves as the fire chamber. Its depth is the stack height combined with the depth needed to add the connecting hole to the bottom.
- Dig a second hole of any diameter, usually between 8-12 inches and up to 24 inches into the ground.

- Dig a third hole in the ground that connects the first two holes and has diameter of about 4 inches. Figure 41 shows all three holes.
- If possible, install a metal grate into the dirt just above the inlet connecting hole.

FIGURE 41: IN-GROUND ROCKET STOVE IMPLEMENTATION

- The burning process begins as any fire. Having fire starter, tinder, kindling, and larger fuel are optimal to start a fire. The fuel is inserted into the top of the stove. Having fire starter, tinder, and kindling initially inserted is best. Light the fire starter. Once kindling is burning, begin adding the larger fuel. Once fire has been started and fuel is lit, continue adding as

FIGURE 42: IN-GROUND ROCKET STOVE TEST

needed. Figure 42 depicts a burning stove.

- Once fire has been started and fuel is lit, continue adding as needed.

6.3.5 Challenges During Testing

Various challenges were encountered during testing times with the most significant of all being a quantifiable way to gauge test results. The reason the team now knows that an in-ground stove performs like a rocket stove is because the Venturi effect was observed, and the former caused rocket (strong air draft) sounds. Furthermore, the team observed less smoke emanating from the in-ground stove than what a three-stone fire would produce. All the observations were captured in pictures and videos via a smartphone. Another challenge the team faced was the time taken and effort invested in starting the fire. During initial tests, it could take upwards of 30 minutes for a fire to start and sustain its burn. The final challenge was the lack of precision in the dimensions of the holes dug. The tools used and the ground did not allow for a 100% certainty in the actual size of holes, and this led to some estimation.

6.3.6 Resolutions to Challenges

The IGSSS proved to be the answer to the team's hole dimension precision challenge. After conducting various tests with even more varying hole dimensions, it occurred to the team lead to design a support system that would incorporate the main ratios for air flow areas. The IGSSS provided the team with consistency in testing and measurements.

A version of the IGSSS that proved to be valuable was the fire extinguisher IGSSS. This version of the IGSSS takes a standard fire extinguisher that would be found in a disaster situation and converts it so it can house a fire. The difference in this version of the IGSSS is primarily that it requires the top of the fire extinguisher to be removed during conversion thereby adding to the overall build time.

The team acquired valuable experience and received help over time from other team members to start fire more efficiently. This resulted in less time being expended and a reduced input effort.

6.3.7 Assessment of Test

The team observed that the in-ground stove performed like a rocket stove. This claim is backed by the fact that during testing, the team experimented with covering the air inlet versus leaving it uncovered. Suffice to say, the team observed that the performance and strength of the fire significantly decreased when the air inlet was covered. This brought about the conclusion that the in-ground stove experiences the Venturi effect and needs that intake of air for the fire to continue burning.

The prototyping of the IGSSS proved extremely valuable because the system performed like a rocket stove. In doing so, it validated the team's thoughts while proving itself to be adaptable and functional in a disaster situation if available.

6.3.8 Revision Recommendations

This year's Field Expediency subteam recommends that future subteams find a more quantitative way to obtain, observe, and analyze data. It might be possible to turn the tests into a DOE with variables, levels, replicates, and test samples. More testing may provide clearer results that would help establish consistency in the rocket stove effect. The team would also recommend further work be done in regards to building the IGSSS using different processes.

7 Integration of Individual Work into Overall Team Project

7.1 Components of the System

7.1.1 Stove

The components of the system are unique because they do not operate in separate units, but build off each other to produce a final completed product of useful information that can be used in developing countries. The initial component of the system is the concrete rocket stoves which produced the data showing that a 1:1.8 inlet to outlet area ratio is ideal. This data was then used to construct the durable, stainless steel stove that was used for gasification testing. This system used aluminum and stainless steel for the core construction, as well as perlite insulation between the chimney and external wall. It included a cross-bracing pot stand design and a central gasification tube. The results from the gasification testing demonstrated the effectiveness of secondary air injection in a rocket stove to reduce carbon monoxide output. The stove and gasification systems resulted in information that can be disseminated in manuals showing effective construction dimensions for rocket stoves. Figure 43 is an example of the components used for testing carbon monoxide output during a design of experiments (DOE). The many considerations that go into these tests are response variables, factors, levels, and constant parameters.

FIGURE 43: TESTING SETUP

7.1.2 Electrical

Throughout the project, the electrical subteam came up with a final design for the electrical generation system. As seen in **Section 5**, the components of the electrical subteam came together to create an electrical system. The team used the TEGs and cooling water reservoir of the IPowerTower™, the new regulation circuit, and the TERSEC to convert thermal energy from the stove into usable electrical energy. The team used the system to charge a cell phone from nothing more than a fire in the rocket stove. Below in Figure 44 is a computer model of the TERSEC. While each component of the system worked individually, the system did not come together to work as planned. The TERSEC over regulated the temperature which caused the hot side temperature of the TEGs to be too low. This resulted in minimal electrical generation. The solution to this problem is to modify the TERSEC to raise the temperature at which the regulation flap cuts off airflow. The team believes this modification will close the loop on an effective generation system and has documented it in the future work section of this report. The IPowerTower™ successfully generated 2 Watts of power with the modified control circuit while using a Sterno Can as a heat source. This implies that the integrated approach to electrical generation, incorporating the reservoir and TEG's of the IPowerTower™ with a new control circuit and regulated heat delivery system, is a verified method of power conversion. The problem of over-regulation with the TERSEC can be modified on future prototypes to acquire the full capability of the system. The future team will be able to continue this work and create a system that will work with the stove as a whole and provide a reliable, safe source of electricity.

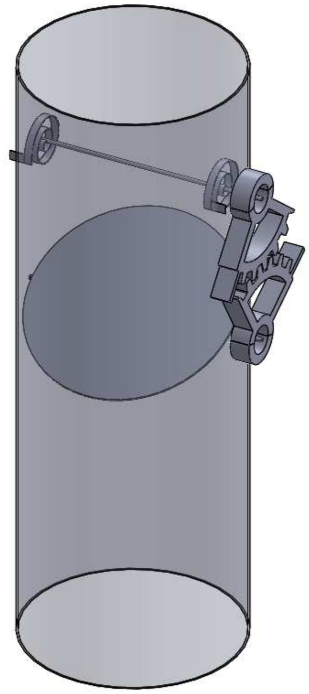

FIGURE 44: TERSEC CAD MODEL

7.1.3 Field Expediency

The Field Expediency team created an independent system to test field applications of rocket stove design parameters. The In-Ground Stove Support System discussed in Section 5.8 incorporates the optimal stove design ratios into its construction and is coupled with a hole in the ground to comprise the entire field expedient aspect of the system. In-Ground Stove Support System also uses the Venturi effect to create the same clean burn as the stove team's stove. These principles and ratios allowed the Field Expediency team to create an independent system.

7.2 Results

7.2.1 Stove Results

7.2.1.1 Pot Accessory

The results from the pot accessory testing broadened the team’s understanding of cooking performance. The team had expected the heat exchanger with the enclosure to perform the best because the heat exchanger theoretically increased the surface contact with the pot and fire. Increased surface contact would transfer more heat from the fire to the pot. However, the results below show the cross bracing with the enclosure performed the best with a ramp rate of 0.306 °C/s. After analysis, the team realized that the reason the heat exchanger did not perform well was because there was less surface contact than expected due to warping in the pot and in the heat exchangers. This problem could be solved by joining the heat exchanger to the pot with hi-temperature JB weld, but the team recognized that the heat exchanger concept would not be feasible in developing countries. This is due to the difficult manufacturing techniques needed to fold metal into the heat exchanger pattern and unavailability of high quality materials and joining methods to make it work effectively. The team found that the simple cross bracing pot support along with the pot enclosure provided the best heat transfer to the pot.

TABLE 9: POT ACCESSORY RAMP RATES

Test (Average of 2 Replicates)	Ramp Rate °C/sec
Cross Bracing Only:	0.284
Enclosure and Cross Bracing:	0.306
Enclosure and Heat Exchanger:	0.269
Heat Exchanger Only:	0.244

7.2.1.2 Statistical Significance

The P-values listed in the results are an indication of whether the data obtained is significant. These values can be interpreted as a probability. For example, the P-value for the interaction effect between stove inlet and the gasification tube is .011. If these certain parameters were to be repeated, there is a 11/1000 chance that there would be a random sampling error. Results are generally accepted if the P-value is less than .050. P-values greater than .050 indicate results that are considered not significant. In these cases, noise or errors in measuring procedures must be reduced or changed.

7.2.1.3 Internal Geometry

This full factorial DOE with 2 factors ranging from 2 to 3 levels tested the heat output (ramp rate) and fire efficiency of different internal dimensions. From these response variables, a third variable was created called the performance ratio that factored the original two response variables. Many valuable conclusions were drawn from this design of experiment that are useful in field dissemination.

TABLE 10: FACTORS AND LEVELS

Factors	Levels		
Outlet Area	9.62 in^2	15.90 in^2	28.27 in^2
Inlet Area	9.62 in^2	15.90 in^2	-

In the top right hand diagram on Figure 45, it is interesting to note the interaction effect based on the outlet area. Observing the blue line, the inlet to outlet of 9.62:15.90 performed better than the 9.62:28.27 because it dissipated heat too expansively. However, the 9.62:9.62 performed worse than the 9.62:15.90 because it constricted the fire too much. This demonstrates that the ideal inlet to outlet area ratio is near 1:1.8 when the ratio is simplified. In the bottom left hand diagram, it is important to note the green line. Notice how significantly the 15.90:28.27 outperforms all other stoves, including the 9.62:28.27 which only has a slightly modified inlet diameter. The interaction effect here is profound, showing that, of two stoves with the same diameter chimneys, the one with a larger inlet that matches the 1:1.8 area ratio will perform remarkably better than one with a smaller air inlet. The 9.62:28.27 configuration is useful, though, demonstrating stove dimensions that would do well for cooking for a family as the smaller inlet provides a more controlled burn optimal for cooking.

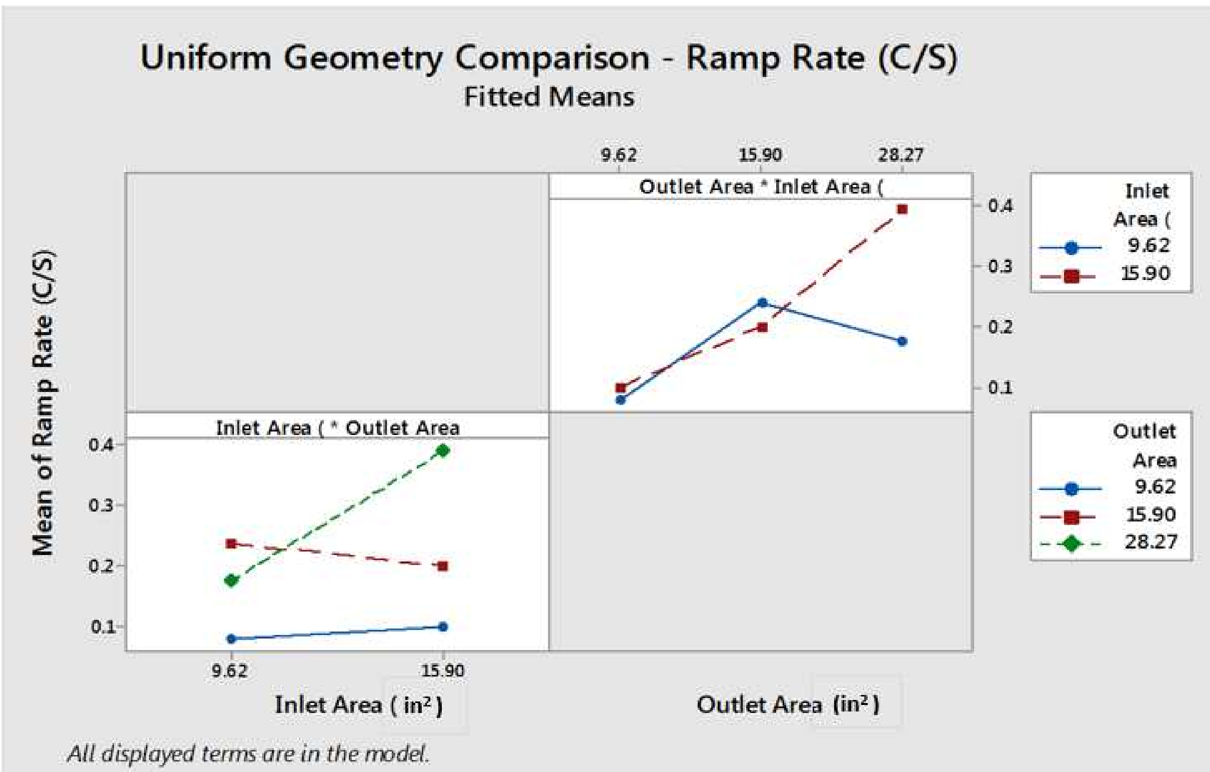

FIGURE 45: GRAPH OF HEAT OUTPUT (RAMP RATE) RESULTS

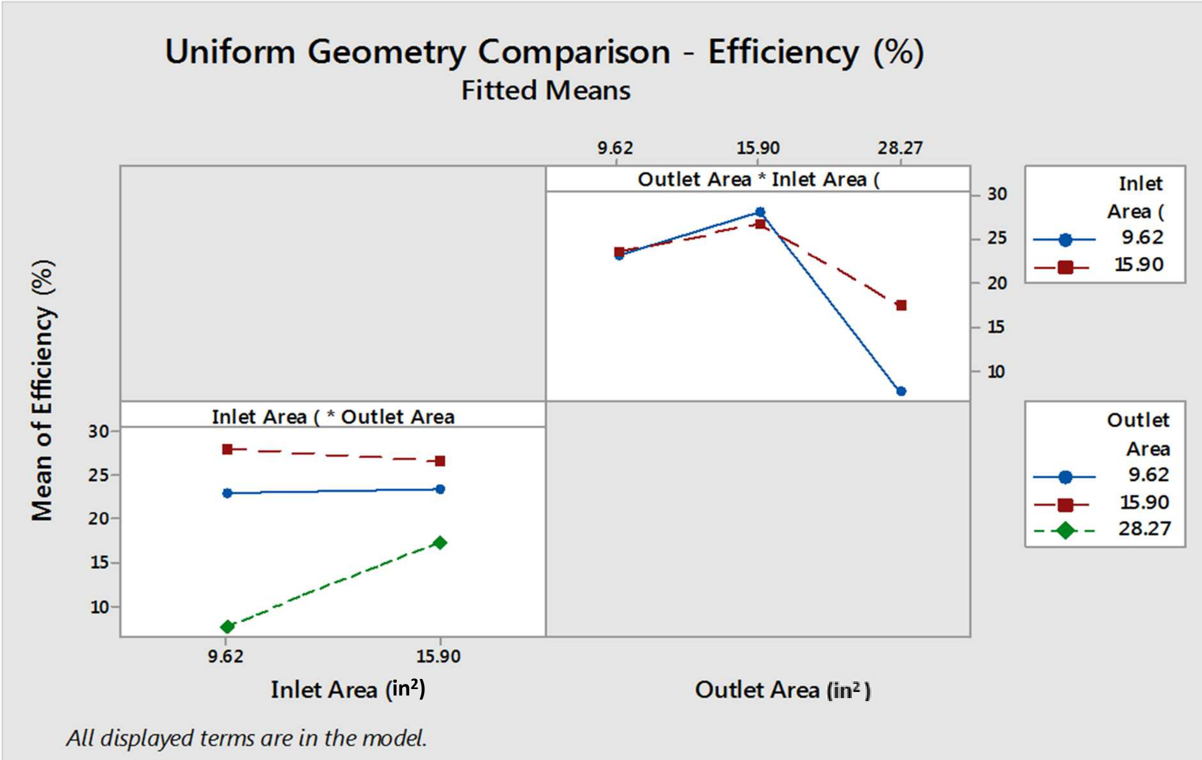

FIGURE 46: FACTORIAL GRAPH OF STOVE EFFICIENCY RESULTS

The efficiency of the various stoves once again points to an inlet to outlet ratio that can either be too small or two large. In the top right hand diagram notice how both lines top out before dropping off. Besides the reasons mentioned previously for the heat output performance, it is also important to note that this graph demonstrates that efficiency is based on outlet area and pot width. Another observation is that, once again, the inlet can be too constricting as the 15.90:28.27 significantly outperforms the 9.62:15.90 (green line) even though it would be assumed the 15.90:28.27 burns more wood. The smaller inlet constricts the air intake and does not allow the fire to achieve complete combustion. The optimal inlet to outlet area ratio that this data supports is 1:1.8. Additionally, the pot used with the stove for cooking should be at least 1.5 times the diameter of the outlet to maximize contact with the flame. The team recognizes that fuel consumption in developing countries and disaster situations is a critical factor, so an extremely fast-burning stove may not be ideal for all situations. Thus, the 1:1.65 inlet to outlet area ratio is a very efficient stove for a 6-inch pot and is recommended for cooking for small families.

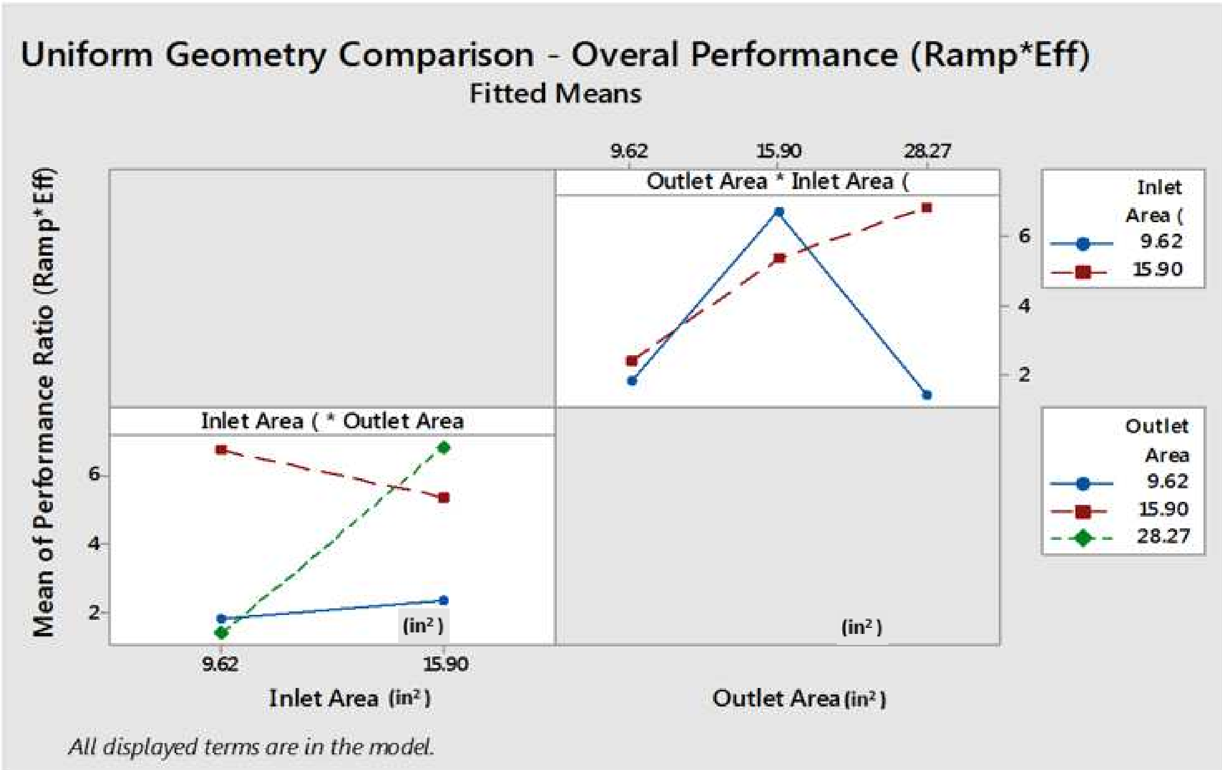

FIGURE 47: FACTORIAL GRAPH OF OVERALL PERFORMANCE

The overall stove performance is valuable information that weighs in the heat output and efficiency. Since these two, performance metrics are multiplied by one another to derive the final value, a high performing stove could be balanced out by a low efficiency, giving more accurate analysis. The 1:1.8 and 1:1.65 area ratios are reaffirmed and even magnified by their close proximity to each other. Note how the blue line peaks out on the top right graph when the inlet to outlet ratio is at 1:1.65. Another observation in the top right graph is the highest blue point and the highest red point. Since these two stoves have about equal overall performance and equal ratios, this proves that stoves can be scaled and still retain excellent performance. Scalability is important information that can be useful for people who cook with rocket stoves because it can help determine the size of stove needed based on the number of people fed from the stove. These area ratios are slightly different than the previous year's ratios. This is due to the way the internal geometry DOE was performed. The previous year's ratios originated from a DOE that used restrictor plates to vary the inlet and outlet areas. Since the internal geometry DOE that was conducted this year fundamentally changes the internal structure, the results differ slightly. As a result, the team believes that the internal geometry DOE is more accurate.

TABLE 11: STATISTICAL ANALYSIS OF INTERNAL GEOMETRY DOE

Term	P-Value
Inlet Area	0.000
Outlet Area	0.000
Interaction Effect	0.000

7.2.1.4 Gasification

The results from measuring the ramp rate of water temperature for various gasification factors and levels proved to be an effective means in determining the feasibility of gasification and the dimensions that produce the prominent secondary burn. The picture below demonstrates a level of 0.166 in^2 air outflow area with an air injection height of 20.50 inches. This picture alone demonstrates the feasibility of gasification while the results in Figure 49 and Figure 50 prove how, at specific parameters, the heat output can increase.

FIGURE 48: OUTFLOW HEIGHT OF 20.50 INCHES

The full factorial matrix below displays the average ramp rate temperature of various levels of the design of experiments. An interesting highlight of the results is the significant increase in stove performance with the increase in height of where the oxygen is being injected. Notice in the right side of the graph how almost all the lines have an impressive increasing slope as the difference between the 12.0-inch height and the 20.50-inch height increase the ramp rate by almost 75%. This conclusion is very firm because the P-value for air inflow height was 0.0001. Another interesting highlight is the fact that with the increase in cross sectional area of gasification inlet, the stove performance decreases. This is due to the Venturi effect. With the increase in air inflow area there is a decrease in the air inflow velocity. The oxygen then loses that injection type effect which is beneficial to gasification. However, this hypothesis should not be heavily considered because the P-value for air outflow area was 0.124.

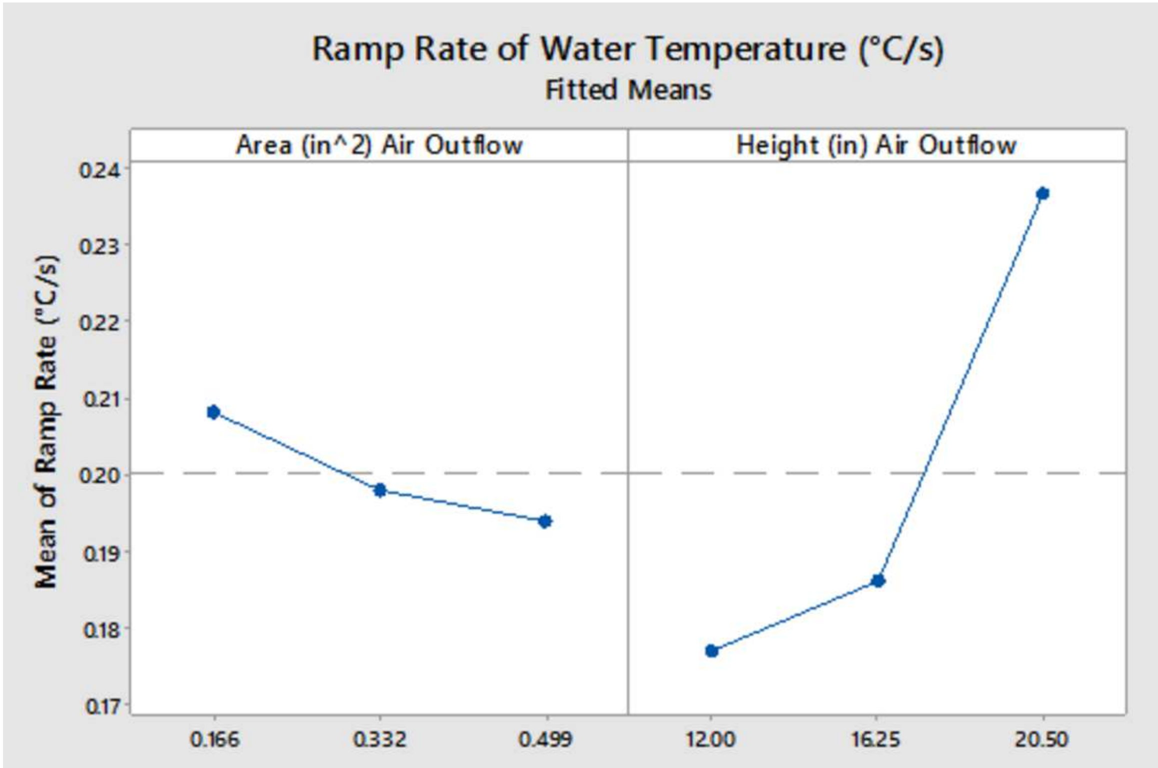

FIGURE 49: FITTED MEANS GRAPH OF RAMP RATE RESULTS

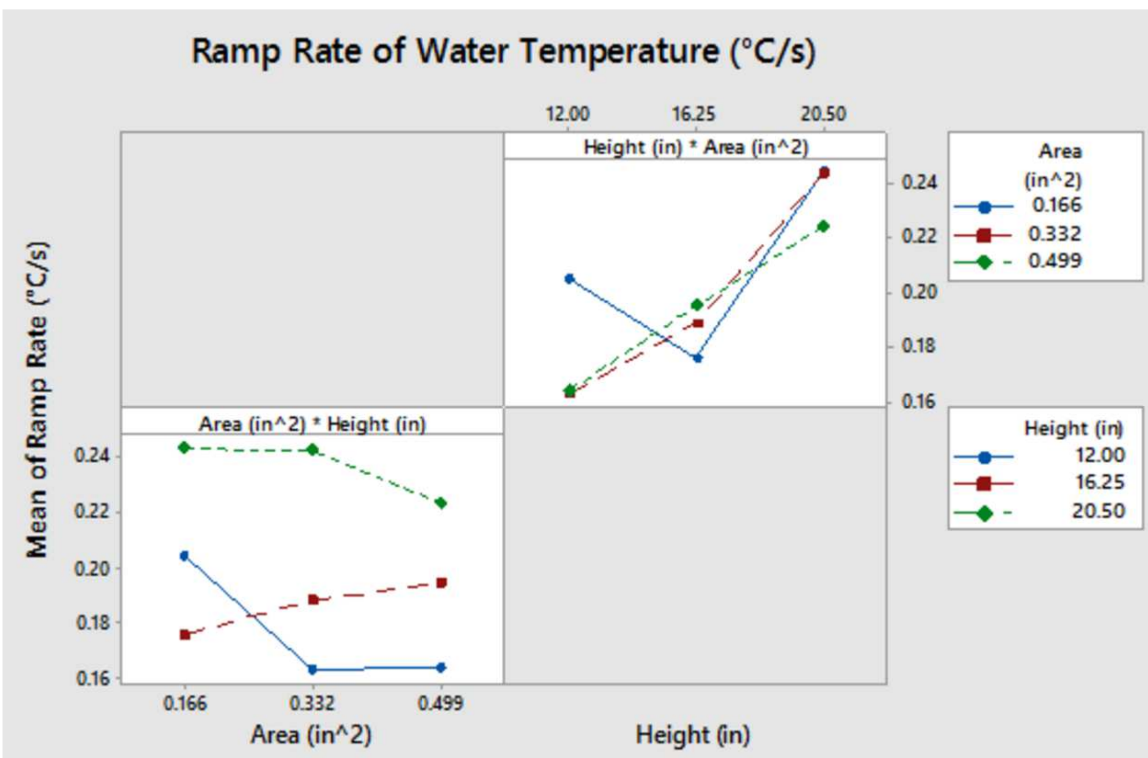

FIGURE 50: FACTORIAL GRAPH OF RAMP RATE RESULTS

TABLE 12: STATISTICAL ANALYSIS OF GASIFICATION RAMP RATE

Term	P-Value
Area	0.124
Height	0.001
Interaction Effect	0.012

7.2.1.5 Carbon Monoxide

After performing carbon monoxide testing on a wide variety of stoves, the results were outstanding in proving that gasification makes the stove beneficial and safer than a three-stone fire. Although there was a design of experiments conducted with rocket stoves, it is important to note that a three-stone fire was also tested as a means of comparison to a system that people use in developing countries.

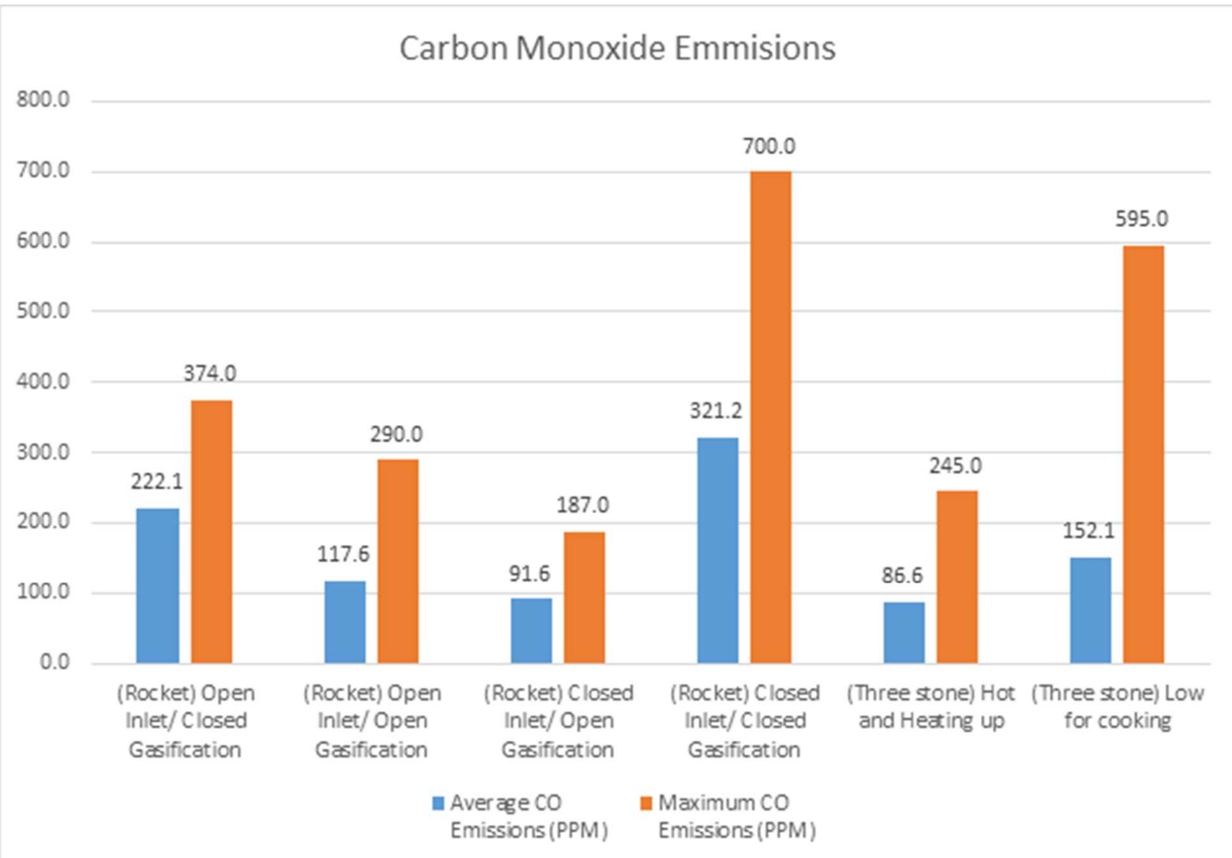

FIGURE 51: CARBON MONOXIDE EMISSIONS

Rocket Stove Only: When solely analyzing the rocket stove results (seen in Figure 51: Carbon Monoxide Emissions), the effect gasification plays is very prominent. From a hot, rocketing fire *(Open Inlet/Closed Gasification)* to a slow burning fire *(Closed inlet/Open Gasification)* the carbon emission was reduced by over half. This is because gasification is most prominent when the stove inlet is closed, and the oxygen being injected at the top of the stove combusts a percentage of the carbon monoxide. Notice in Figure 51 how the average CO emission dropped from 222.1 PPM to 91.6 PPM between data set one and three.

Three Stone Fire Only: The results for a three-stone fire, optimized for cooking indicate that its poses major health concerns. The *hot and heating up* three-stone fire data set indicates that there is not much concern when initially starting a fire as the PPM was at 86.6. However, there are still large spikes in the CO emission as seen with the maximum value of 245.0 PPM. When the stove is set to *low for cooking* which includes hot coals and only small flames, there is a massive increase in CO emission. The primary concern is the 595.0 PPM maximum carbon monoxide output which is an extreme level that can kill a person in less than 3 hours.[27]

Comparing stove versus three-stone: When comparing the two different types of fires, it is most important to analyze the stoves and configurations that are used for cooking (data set three and five). The steel rocket stove produced almost half the CO emissions as the three-stone fire produced when under cooking conditions. Additionally, what is not seen in the data is the fact that the rocket stove has a significantly cleaner burn with less visible particulates than the three-stone fire. Figure 52 (left) shows smoldering coals, but when these coals were added into an empty rocket stove (right), they immediately burst into flames.

FIGURE 52: SMOLDERING COALS (LEFT) IGNITED COALS (RIGHT)

Design of Experiments - Rocket Stove Carbon Monoxide Emission: The full factorial design of experiments had two factors with two levels each, as seen in Table 7 (page 59). This test verified the above conclusions by giving P-Values of 0.000 for gasification and 0.011 for interaction effect. The P-value of the gasification tube factor demonstrates that whenever oxygen is added into the smoke stream it reduces the amount of carbon monoxide emission. Additionally, the interaction effect between the stove inlet and the gasification tube shows

[27] "Carbon Monoxide Levels and Risks." National Comfort Institute, Inc. Available: http://www.myhomecomfort.org/wp-content/uploads/2015/09/CO_Levels_Risk_Chart.pdf. Accessed: February 2017

an interesting result. When the gasification tube is open but the stove inlet is closed, carbon monoxide emissions are reduced even though the fire is receiving less oxygen compared to when the stove inlet is open. The hypothesis for why this is true is due to the team's process of gasification. The high level of effectiveness in reducing carbon monoxide emission would not occur without properly preheating the stove, adding fuel, and closing the inlet.

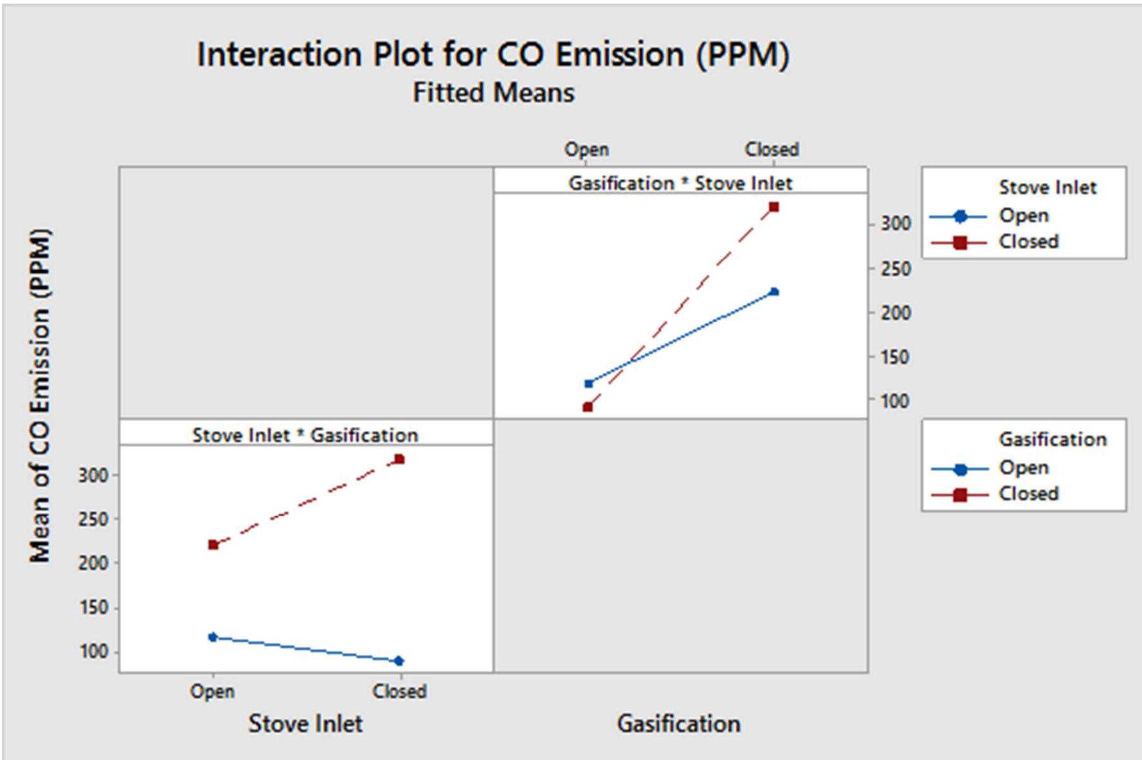

FIGURE 53: FACTORIAL GRAPH OF CARBON MONOXIDE EMISSIONS

Term	P-Value
Stove Inlet	0.092
Gasification Tube	0.000
Interaction Effect	0.011

TABLE 13: STATISTICAL ANALYSIS OF CARBON MONOXIDE DOE

7.2.2 Electrical Results

7.2.2.1 Thermoelectric Power Generation with TEGs

The electrical part of the project used a TEG to convert the thermal energy to electrical energy. To do that the team needed to be able to measure the power outputted by the TEG. The team first looked at ways to measure the power output of a TEG. The team was able to calculate the power of the TEG by measuring the current and voltage of a TEG charging a cell phone. With the current and voltage values, the simple equation of $P = V * I$ is used to calculate the power. After multiple tests of the IPowerTower, it was found that, with using a Sterno Can, an output of 2 Watts was easily obtained. When combining the IPowerTower with the TERSEC, the same results were not obtained as the TERSEC over limited the temperature.

7.2.2.2 Regulating Temperature on Hot Side of Thermoelectric Generator

As seen in Section 5.6, the TERSEC was used to control temperatures on the hot side of the TEG. To achieve maximum power, the temperature differential for the TEG must be as high as possible. However, there is an upper limit for the temperature, since the semiconductors inside the TEG will begin to melt at around 300°C and cause system failure. The TERSEC was therefore necessary to maximize performance. The bimetallic coils were cut to the appropriate length so that the flap letting hot air through to the TEG's would be fully closed just before 250°C. This length was chosen based on the angular deflection formula for bimetallic coils,

$$\alpha = \frac{2a(T - T_0)L}{s} \cdot \frac{360}{2\pi}$$

Where α is (T – T_0)angular rotation in degrees, a is the specific deflection of the material (a constant depending on bimetal material), s is the thickness of the bimetal, and L is the bimetal length. Through empirical testing of the team's bimetal coils salvaged from stove thermometers, the constant $\frac{a}{s}$ was determined to be $6.23 \cdot 10^{-5}$, therefore the equation became

$$\alpha = 6.23 \cdot 10^{-5} \cdot 2(T - T_0)L \cdot \frac{360}{2\pi}$$

Setting $(T - T_0)$ to 225°C (assuming 25°C ambient), and α to 90 degrees, the rotation required to fully close the flap, the desired length to cut the bimetal coil was discovered:

$$90 = 6.23 \cdot 10^{-5} \cdot 2(225)L \cdot \frac{360}{2\pi}$$

$$L = 56\,mm$$

The bimetal coils were therefore cut to this length and re-coiled.

TERSEC testing was very successful, and its benefit was proven when compared without its implementation. As seen in Figure 54, The temperature at the thermocoils remained below the 300°C threshold for damage, peaking at 250°C, as expected. The TERSEC therefore provides an effective mechanical method for maximizing power to the TEG's without damage. However, in pursuit of TEG safety over performance, the team overlooked the heat loss that occurs after the TERSEC, through conduction to the water on the other side of the TEG's, and through fin efficiency of the heat sink on the TEG's. This resulted in overregulation. The temperature provided to the TEG's after the TERSEC was much lower than the air that passed through the outlet of the TERSEC, which hindered TEG performance. For future work, the team plans to calculate the heat losses that occur past the TERSEC outlet and implement them into the bimetallic coil configuration in order to more effectively control TEG hot side temperature.

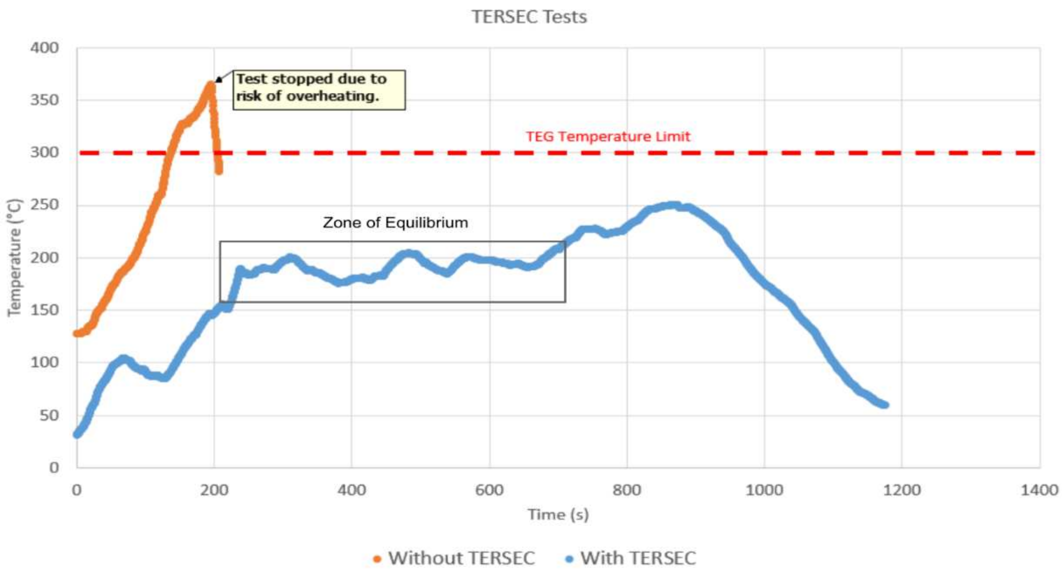

FIGURE 54: TERSEC TEMPERATURE RESULTS

As seen in Figure 54, once the stove warmed up, the TEG's would reach a zone of equilibrium where the flap was semi-closed. This was the result of the intended feedback loop between the temperature of the bimetal coils and the rotation of the heat flap. As the temperature of the coils increases, the heat flap closes off hot air, and the temperature of the coils subsequently decreases. This allows the TEG's to experience a constant temperature regardless of fire performance. If the fire is allowed to burn too hot, the heat flap eventually closes off completely and airflow to the TEG's is halted until a lower temperature is restored.

7.2.2.3 Controlling the Cold Side of Thermal Electric Generator

Three cooling methods were tested for providing a cold side for the TEG as seen in Section 5.5. The first method was a simple, natural air-cooled method which relied completely on convection through vertical, aluminum cooling fins located on the cold side of the TEG. This first method proved to be ineffective and produced almost no power. The second cooling method was similar to the first, but relied on forced air convection using a fan. The forced air convection was induced by placing a large fan in front of the heatsink. This worked better than the natural convection, producing half a Watt of power. The final cooling method consisted of a water reservoir which confined the cold side temperature to 100°C provided that the water was not permitted to boil off. This method proved to work the best, providing an output of 2 Watts.

7.2.3 Field Expediency Results

7.2.3.1 In-ground Stove

Testing of the in-ground stove was successful in meeting the team's initial goals. Through testing results and observation, evidence leans towards the reality that the in-ground stove is a feasible, cheap, and effective cooking alternative to traditional practices. The Venturi effect was observed and rocket sounds heard throughout testing, meaning that the in-ground stove performed like a rocket stove. Fire performance and strength were observed to significantly decrease when the air inlet was covered and then return to full burn when uncovered. Digging the stove deeper into the ground provided a taller chimney and better stack effect as opposed to surrounding it with bricks. Ultimately, the design of the in-ground stove support system provided the team with a solid model that incorporated results from in-ground stove tests as well as rocket stove geometry and ratios tested and established by the stove team.

8 Conclusion

8.1 Conclusion

The 2016-2017 Disaster Relief Solutions team used a heuristic testing approach to investigate effects of air inlet area to air outlet ratios and gasification on rocket stove performance, research practical applications of rocket stove technology, and implement a self-contained phone charging system that converts heat to electricity. The team discovered that the air inlet area to air outlet area ratio is extremely significant to improving stove performance, and the optimal ratio is 1:1.8. Gasification testing indicated that secondary burn causes a more complete combustion, reducing the number of carbon monoxide and particulate emissions. It also showed, however, that gasification is independent of the amount of airflow injected into the stove, since the fire uses the Venturi effect to draw in as much as is needed to combust the smoke. The team also found that the IPowerTower™, which uses a water reservoir for the cold side temperature regulation, was an effective way to make electricity generation from the stove feasible. A self-regulating air duct designed by the team, labeled TERSEC, channeled super-heated air from the rocket stove to the TEG array while limiting the airflow in order to prevent overheating the TEG. The team also constructed a circuit to convert the variable output from the TEGs into a useable, 5 Volt charging station. Initial testing of the electricity generated using the IPowerTower™ and regulation circuit charged a cell phone, providing 2 Watts of power. Final testing with the entire system validated the concept but showed that the TERSEC over-limited the heat input. The team successfully generated measurable power using the combined system and documented valuable lessons that will allow the future teams to build upon these concepts.

The results of this year's testing have shown that rocket stoves are a useful, expedient tool for use in any disaster situation or developing country where resources are scarce. Using the stove geometry ratios found in the stove DOEs, a high-performance rocket stove can be built using nearly any material type. As an example of this, the Field Expediency subteam constructed an inground rocket stove that simply uses a single aluminum pipe for the chimney. Once buried in the ground and vented with a second air inlet hole, this device exhibits rocket-like performance, easily cleans up, and puts off little smoke. When coupled with an electricity generation tool, the rocket stove's full potential is harnessed as it produces enough heat to be converted into useful power.

8.2 Achievement of Objectives

The Disaster Relief Solutions team has met its primary goals in rocket stove research, design, and heat-electricity conversion. Using Design of Experiments with a series of rocket stoves built by the team, the optimal stove inlet area to stove outlet area ratio of 1:1.8 was established. Gasification testing was also completed using two Design of Experiment processes, and found that the amount of air injected is not significant but the height at which the air is injected greatly affects cooking performance. Air quality, however, improves drastically when secondary burn is present, as carbon monoxide output dropped nearly 50% when secondary air was injected into a high performing rocket stove. Compared to an open cooking fire, the rocket stove in its cooking configuration produced 40% less carbon monoxide. Testing of the rocket stove with a pot skirt was moved to future work, as the team chose to invest more time into investigations of gasification on smoke. The TERSEC device designed by the electrical subteam worked well self-regulating the temperature, however, the TERSEC did over limit the temperature. The TERSEC design was proven to work but still needs some modification. With using a Sterno Can in place of the TERSEC, a continuous charge to a cell phone was obtained with little user input. The team's website has been updated to reflect the most current findings, and includes the five publication documents: in-ground stove technical guide, in-ground stove pictorial guide, IGSSS pictorial guide, rocket injector stove technical guide, and a rocket injector stove pictorial guide. These documents can also be found in the appendices. The website is located at: http://www.letu.edu/_Academics/Engineering/student-projects/disaster-relief/Stove_Design.html

8.3 Recommendations and Future Work

8.3.1 TEG Forced Air Cooling

With the success of water cooling, air cooling should be considered for places with little access to water. Air cooling was difficult to use, but with further research and testing, it could be possible. Using fans to force more air over a heatsink would be the best option for keeping the TEG cooler. Also, by using air to cool the TEG, a better source of heat could be created. Having a heatsink to dissipate heat would allow for more heat to be produced for the user.

8.3.2 Combination of Cooling TEG and Heating Water for Cooking

The team would like to explore other designs for the water reservoir that could better assist in cooking. If the water container was changed from the current design of the IPowerTower™, more water could be heated and used for cooking. Also, a different physical design of the reservoir that allowed for better space management would be useful.

8.3.3 Self-Regulating TEG Hot Side

For future TEG considerations, the team recommends considering other ways to help regulate the heat applied to the TEG. The current solution works well but could be improved upon. Being able to adjust the TERSEC so that the regulation flap closes at different temperatures while in use would make testing much more efficient. The team would like to see continuation of the TERSEC.

8.3.4 Electronic Dissemination

The team, as a whole, gathered valuable information with regards to designing and building an efficient rocket stove and how this information can be used and adapted to a variety of situations. In the future, the team web page should be updated each year to include each year's updated information in an apparatus which is easy to access and use.

8.3.5 In-Ground Stove Support System

The team designed and built a stove support system that can be deployed to disaster situations using scrap metal and processes that are easily accessible in the United States. The team would like to see further work done in regards to building the support system in a true disaster situation with minimal processes available.

8.3.6 Gasification Effects on Efficiency

After this year's progress on gasification testing, the team believes that further work will be helpful to examine interaction effects between stove geometry and gasification air flow volume and injection height. The testing design this year eliminated any changes in stove geometry, but the team believes that these may significantly affect the amount of air needed for gasification and optimal secondary air injection design. Future work done in this area must identify appropriate response variables, such as water boil ramp rate, carbon monoxide output, and fire efficiency in order to obtain useful results.

8.3.7 Induced Turbulent Airflow

The literature review suggested that obstructions in the chimney induce turbulence in the airflow through the rocket stove and provide a more complete combustion. This could be explored with comparison testing to compare carbon monoxide output between turbulent and laminar airflows.

8.3.8 Temperature Mapping

By capturing and mapping the temperatures on all parts of the rocket stove, the team could better optimize the stove's materials and dimensions. It would be useful to ensure that appropriate materials are used in each part of the stove to withstand varying levels of thermal shock.

8.3.9 Scalability

Changing the size of a rocket stove may affect the optimal stove geometry ratios due to scaling factors. The DRS team has seen indications that this does not significantly alter stove design parameters, but believes that further testing is necessary to provide decided proof. Testing could be done by constructing nine rocket stoves with three different air inlet to air outlet ratios at three different scales. For example, the 4:6 inlet to outlet diameter ratio may be used for one level, and would be constructed at scales of ½, 1, and 1 ½, or 2:3, 4:6, and 6:9.

8.3.10 In-situ Material Testing

The material used in rocket stove construction drastically affects the stove's performance, warm up time, and heat storage capacity. In-situ materials from developing countries such as clay, brick, and dirt will alter the construction methods used to produce a stove and change the behavior of the fire. DRS believes that future testing with rocket stoves built from brick and other simple materials will provide insights into optimal materials, design changes based on material properties, and technical information for dissemination to developing countries.

8.3.11 Insulation Wall Thickness

This year, the DRS team conducted COMSOL analysis and hand calculations to analyze the optimal wall thickness for a circular rocket stove, but further physical testing would be useful to validate the conclusions. Testing could include a metal test stove such as the team has used as its primary DOE stove, coupled with a method to adjust the thickness of insulation between the burn chamber and the outside of the rocket stove. An insulated burn chamber is one of the key factors in obtaining the high performing rocket stove characteristics, but a quantified thickness parameter would enhance future stove designs.

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10 Appendices

Appendix A Team Project Summary Pamphlet

Team Info

Faculty Advisor—Dr. Scott Anson, PE
Team Lead—Nathan Hughes

Stove Subteam
Lead—Taber Miyauchi
Mark Claypool
Sean Eldridge
Hunter Rose

Electrical Subteam
Lead—Samuel Beans
Evan Boone
Jared Wende

Field Expediency Subteam
Lead—J.T. Hevrin
Lionel Tchekane Alama
Brandon Farrar

Disaster Relief Solutions

For more information or to contribute to our project, visit our website or contact Dr. Anson at scottanson@letu.edu or

http://www.letu.edu/_Academics/Engineering/student-projects/disaster-relief/

Disaster Relief Solutions

Heat, cooking, electricity

Team Project Summary

DRS DISASTER RELIEF SOLUTIONS

Mission Statement

Using God-given intellect fueled by compassion, Disaster Relief Solutions is heuristically designing a low-fuel, clean-burning stove to cook food and charge electronic devices in developing countries and emergency situations.

Motivation

Living conditions East of Eden can and should be improved

Genesis 3:24 "After he drove the man out, he placed on the east side of the Garden of Eden cherubim and a flaming sword flashing back and forth to guard the way to the tree of life."

Stove Design

This subteam designs and tests various parameters of rocket stoves in order to optimize the most efficient, effective, and user-friendly design for field application.

The subteam performed computational analysis of stove wall insulation thickness, designed and constructed experimental specimens for inlet/outlet ratios and a DOE for optimizing gasification.

Electrical Generation

This subteam works to generate electric power from a rocket stove. They used thermoelectric generator (TEG) for generating power to charge a phone.

They tested a TEG under controlled test conditions to ensure no overheating with a phone to ensure feasibility. The Temperature Regulating System for Electrical Components (TERSEC) was developed to protect electronics from overheating.

Field Expediency

This subteam acts a mediator between research and testing within the team and real world application.

So DRS could better design stoves, they performed interviews with people who had experience in other countries where the stove may be used. These interviews have given insight into how the stove can best be designed to operate in these areas.

This part of the team has also verified the application of an in-ground stove, an in-ground support system (IGSSS), and published information on the team's findings.

Appendix B Rocket Stove Assembly Pamphlet

Team Info

Faculty Advisor—Dr. Scott Anson, PE
Team Lead—Nathan Hughes

Stove Subteam
Lead—Taber Miyauchi
Mark Claypool
Sean Eldridge
Hunter Rose

Electrical Subteam
Lead—Samuel Beans
Evan Boone
Jared Wende

Field Expediency Subteam
Lead—J.T. Hevrin
Lionel Tchekane Alama
Brandon Farrar

Purpose:

A rocket stove is used to provide an efficient heating and cooking method. This simple design uses less fuel while providing ample heat.

Disaster Relief Solutions

For more information or to contribute to our project, visit our website or contact Dr. Anson at scottanson@letu.edu or

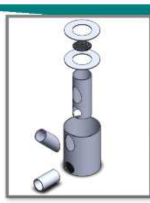
http://www.letu.edu/_Academics/Engineering/student-projects/disaster-relief/

Disaster Relief Solutions

Heat, cooking, electricity

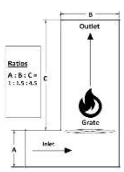
Rocket Stove Assembly Guide

DRS
DISASTER RELIEF SOLUTIONS



Materials:

- Inner and outer pipe
- Metal grate
- Insulation (e.g. Perlite)
- Stove inlet tube
- Fuel feeding tube
- Pot stand
- Cap (for fuel feed)
- Sheet metal
- High temp adhesive/welds
- L-Brackets (use as fasteners)
- Nuts and bolts or metal rods



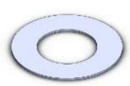
Ratios:

- Stove inlet diameter to outlet diameter to stack height from the grate are 1:1.5:4.5
- The inner pipe to the outer pipe diameter ratio should be 1:2

1 Secure grate to outlet pipe with bolts or rods

2 Put outer pipe around the outlet pipe

3 Cut holes for air inlet and angled fuel feed pipes



4 Cut washer shape from sheet metal to fit between pipes

5 Install sheet metal above inlet hole

6 Install inlet and feed pipes with adhesives/welds

7 Fill insulation between inner and outer pipes.

8 Install second washer shape on top of the stove

Example Stove

A cap should be added on the fuel feed pipe during burning to prevent airflow.

Appendix C In-Ground Stove Pamphlet

Team Info

Faculty Advisor—Dr. Scott Anson, PE
Team Lead—Nathan Hughes

Stove Subteam
Lead—Taber Miyauchi
Mark Claypool
Sean Eldridge
Hunter Rose

Electrical Subteam
Lead—Samuel Beans
Evan Boone
Jared Wende

Field Expediency Subteam
Lead—J.T. Hevrin
Lionel Tchekane Alama
Brandon Farrar

Purpose:

The in-ground stove is a functional form of a rocket stove which uses fewer materials to build. This stove improves heating and cooking efficiency.

Disaster Relief Solutions

For more information or to contribute to our project, visit our website or contact Dr. Anson at scottanson@letu.edu or

http://www.letu.edu/_Academics/Engineering/student-projects/disaster-relief/

Disaster Relief Solutions

Heat, cooking, electricity

In-Ground Stove Assembly Guide

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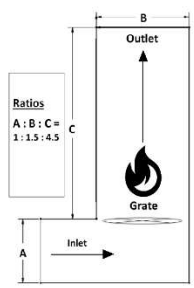
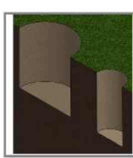
Materials:

- Digging tools
- Metal grate

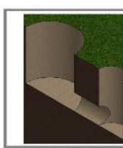


Diagram

1
Dig outlet hole to ratio given.



2
Dig a second hole of any size next to the first.



3
Dig inlet hole to connect them using ratios.

4
Install grate in the dirt above the inlet hole.

Implementation

1
Dig outlet hole to ratio given.

2
Dig a second hole of any size next to the first.

3
Dig inlet hole to connect them using ratios.

Appendix D IGSSS Pamphlet

Team Info

Faculty Advisor—Dr. Scott Anson, PE
Team Lead—Nathan Hughes

Stove Subteam
Lead—Taber Miyauchi
Mark Claypool
Sean Eldridge
Hunter Rose

Electrical Subteam
Lead—Samuel Beans
Evan Boone
Jared Wende

Field Expediency Subteam
Lead—J.T. Hevrin
Lionel Tchekane Alama
Brandon Farrar

Purpose:

The in-ground stove support system is a functional and easily deployable form of an in-ground stove accessory. This stove improves heating and cooking efficiency.

Disaster Relief Solutions

For more information or to contribute to our project, visit our website or contact Dr. Anson at scottanson@letu.edu or

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Disaster Relief Solutions

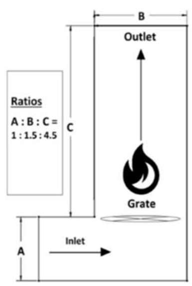
Heat, cooking, electricity

In-Ground Stove Support System (IGSSS) Assembly Guide

DRS
DISASTER RELIEF SOLUTIONS

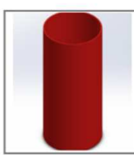
Materials:

- Fire Extinguisher
- Metal grate
- Cutting tools
- (Optional: use metal pipe instead of fire extinguisher.)

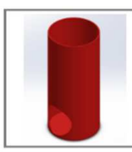


Diagram

1 Select a fire extinguisher.

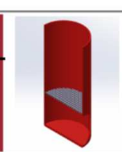


2 Cut the top off of the fire Extinguisher.



3 Cut out the inlet hole.

4 Install grate in the fire extinguisher.



Implementation

1 Select a fire extinguisher.

2 Cut the top off of the fire extinguisher.

3 Cut out the inlet hole.

4 Insert into the ground with second hole as air inlet.

Appendix E Rocket Stove Technical Guide.

Disaster Relief Solutions

JT Hevrin, Brandon Farrar, Lionel Tchekane

Spring 2017

Rocket Stove Construction Technical Guide

Introduction

Background

Disaster Relief Solutions is working to bring relief and higher quality of life to people in disaster situations and developing countries by using God-given intellect to optimize a biomass-fueled rocket stove. The rocket stove is aptly suited to meet the cooking and heating needs of these people groups as it burns cleanly and efficiently and can be manufactured from in-situ materials. Disaster Relief Solutions is working toward providing a safe, clean, efficient alternative to traditional fires or fossil-fueled stoves.

The main design aspect of the rocket stove is to have some sort of structure which supports the main ratios for air flow diameters. The rocket stove design integrates the Venturi effect. The combination of the heat and rocket stove dimensions creates an ideal atmosphere to create an efficient, clean burning stove.

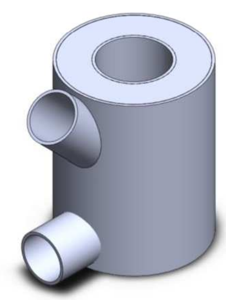


Figure 1: Rocket Stove Rendering

Materials

- Inner and outer pipes
- Metal grate
- Insulation (e.g. Perlite)
- Stove inlet tube
- Feeding tube
- Pot stand

- Cap (for fuel feed)
- Sheet metal
- High temp adhesive/welds
- L brackets
- Nuts and bolts or rods

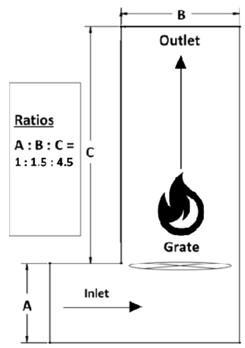


Figure 2: Burn Chamber Ratio Illustration

Procedure

Ratios

The ratios for the stove inlet hole, outlet hole, and stack height from the grate are 1:1.5:4.5 respectively as shown in Figure 2. The inner pipe to the outer pipe diameter ratio should be 1:2.

Building

1. The main dimensions of the burn chamber are driven by the ratios provided. Using sample dimensions, the process begins by using a metal pipe that is 6 inches in diameter and 22 inches long. A 22-inch pipe allows a 4-inch air inlet pipe to be installed at the bottom of the burn chamber while keeping the ratios accurate.
2. If using the rods instead of the bolts, cut 1/8-inch round bar into two pieces about the length of the diameter of the pipe.
3. Drill four holes into the pipe perpendicular to the outlet hole, two on each side of the top of the inlet hole and lined up with the hole opposite. These holes need to be the same diameter as the diameter of the round bar or bolts.

4. Insert the round bar or secure the nuts and bolts through those holes. They will hold the grate in place.
5. Install the grate by inserting it into the pipe opposite the inlet hole until it rests on the bolts or round bars as shown in Figure 3.
6. If possible, weld or use high temperature adhesive to hold the round bar pieces in place once the grate is installed.
7. Set the 12-inch pipe around the 6-inch pipe.
8. Cut a hole from the bottom edge into the side of the both pipes that is large enough to accommodate the air inlet pipe. The outlet diameter should be 1.5 times that of the air inlet pipe.
9. Make a hole above the air inlet pipe where a pipe will be installed later at about 45 degrees. These cuts are shown in Figure 4.

Figure 3: Grate Resting on Rods

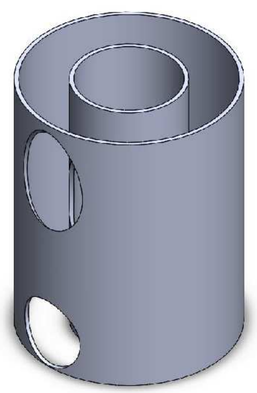


Figure 4: Inner and Outer Pipes with Holes Cut

10. Attach the 4-inch diameter air inlet pipe into the holes cut in the bottom.
11. Cut a washer-shaped piece of sheet metal which is flush with the interior of the 12-inch diameter pipe and the exterior of the 6-inch pipe as shown in Figure 5. Fasten L-brackets on either side of the stove to hold the metal sheet in place level with the grate.

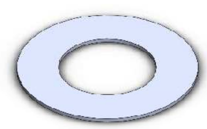


Figure 5: Sheet Metal

12. Attach the fuel feeding pipe so that it settles directly above the grate. Use a high temp adhesive or weld to keep the pipe secure.
13. Carefully pour available insulation around the outlet and let it settle completely on top of the sheet metal cut.

14. Cut another washer-shaped circle with the same dimensions to cover the top of the stove. Fasten L-brackets on either side of the stove to hold the metal sheet in place. The metal parts of the stove should fit together as shown in Figure 6.

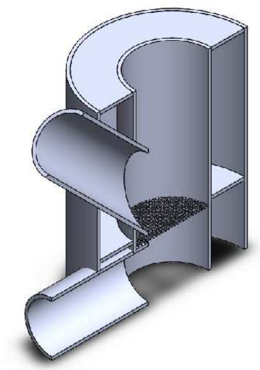


Figure 6: Cross Section of Rocket Stove

Figure 7: Example Rocket Stove

Burning

Once stove has been set up, starting a fire ensues. Having fire starter, tinder, kindling, and larger fuel are optimal to start a fire. The fuel can be inserted into the feeding tube of the stove. Having fire starter, tinder, and kindling initially inserted is best. Light the fire starter. Once kindling is burning, begin adding the larger fuel. Once the large fuel is lit, continue adding more as needed and seal the feeding pipe with some sort of cap. Beware when removing it as the smoke and air could combust upon opening. In the absence of the feeding tube, insert the fuel through the chimney. Keep the air inlet free to allow undeterred air flow to keep fire going.

Having a pot stand holds the pot above the fire and keeps any cooking supplies from sealing the outlet which could impair efficiency.

Conclusion

As the stove heats up, air rises and pulls more air from the inlet hole. This starts a process which continually pulls air faster until it creates a sound like a rocket, giving the rocket stove its name. The additional air helps to heat up the fire and smoke creating a more efficient and complete combustion of the fuel. The rocket stove is an optimal solution to situations where a heating and cooking method is required.

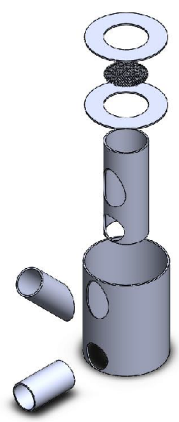


Figure 8: Exploded View of Rocket Stove

Appendix F In-Ground Stove Technical Guide

Disaster Relief Solution

JT Hevrin, Brandon Farrar, Lionel Tchekane

Spring 2017

In-Ground Rocket Stove Technical Guide

Introduction

Background

Disaster Relief Solutions is working to bring relief and higher quality of life to people in disaster situations and developing countries by using God-given intellect to optimize a biomass-fueled rocket stove. The rocket stove is aptly suited to meet the cooking and heating needs of these people groups as it burns cleanly and efficiently and can be manufactured from in-situ materials. Disaster Relief Solutions is working toward providing a safe, clean, efficient alternative to traditional fires or fossil-fueled stoves. This design was adapted to be able to work without a standing structure.

The main design aspect of the rocket stove is to have some sort of structure which supports the main ratios for air flow diameters. The rocket stove design integrates the Venturi effect. The combination of the heat and rocket stove dimensions creates an ideals atmosphere to create an efficient, clean burning stove. The in-ground stove satisfies this need without using as many materials as a traditional rocket stove.

Option 1: Basic Ground Stove

- Metal grate

Option 2: In-ground Stove Support System (IGSSS)

- Metal grate
- Metal pipe
- Nuts and bolts or rods

Procedure

Ratios

The ratios for the stove inlet hole, outlet hole, and stack height from the grate are 1:1.8:5.4 respectively as shown in Figure 2.

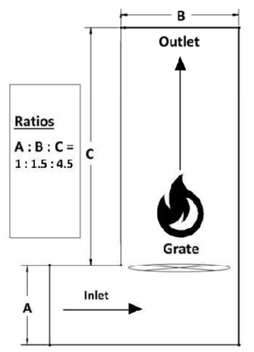


Figure 1: Ratio Illustration

Building

Option 1: Basic Ground Stove

Figure 2: 12" and 6" Holes

1. Using sample dimensions, the process begins by digging a hole that is approximately 6 inches in diameter and 22 inches deep as an outlet hole.
2. Dig a hole a short distance away from the first with a diameter within a range of 6-12 inches. The first holes are exemplified in Figure 2.
3. Connect the holes with a third that runs between the two with a diameter of 4-inch. The top of the third hole should be 18-inch from ground level. This is illustrated in Figures 4 and 5.
4. If available, insert a metal grate into the hole which rests just above the connecting inlet hole to support the fuel.

Figure 4: 4" Connecting Hole

Figure 3: Laser Indicating Presence of Connecting Hole

Option 2: In-Ground Stove Support System (IGSSS)

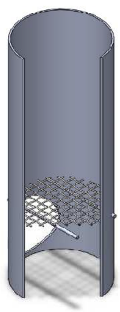


Figure 5: Section View of IGSSS

1. Find a pipe with dimensions corresponding to the ratios provided. An example dimension for the pipe is 6 inches in diameter and approximately 22 inches tall as seen in Figure 6.
2. Find material suitable for aa grate. A grate with medium size holes which can allow ash to easily fall through and made of stainless steel is preferable. Other metals are adequate but will not last as long.
3. Cut the grate in the shape of the pipe's hole diameter.
4. Cut a hole into the side of the pipe that is approximately 4 inches in diameter (or a size which satisfies the given ratio) at the bottom of the pipe as seen in Figure 7.

Figure 6: Sample Pipe

5. If using the rods instead of the bolts, cut 1/8-inch round bar into two pieces about the length of the diameter of the pipe.
6. Drill four holes into the pipe perpendicular to the outlet hole, two on each side of the top of the inlet hole and lined up with the hole opposite as seen in Figure 8. These holes need to be the same diameter as the diameter of your round bar or bolts.
7. Insert the round bar or secure the nuts and bolts through those holes. They will hold the grate in place.

Figure 7: 4" Hole Cut

8. Install the grate by inserting it into the pipe opposite the inlet hole until it rests on the bolts or round bars as shown in Figure 9.
9. If possible, weld the round bar pieces into place once the grate is installed.

Figure 9: Round Bar Holes

Figure 8: Bottom View of Grate

Burning

If using the IGSSS, insert it into the 6-inch outlet hole. This will support the hole and ensure accurate dimensions. Be sure that the pipe's inlet hole faces the inlet hole that is dug.

The burning process begins as any fire. Having fire starter, tinder, kindling, and larger fuel are optimal to start a fire. The fuel is inserted into the top of the stove. Having fire starter, tinder, and kindling initially inserted is best. Light the fire starter. Once kindling is burning, begin adding the larger fuel. Once the large fuel is lit, continue adding more as needed.

Figure 10: In-ground Stove in Use

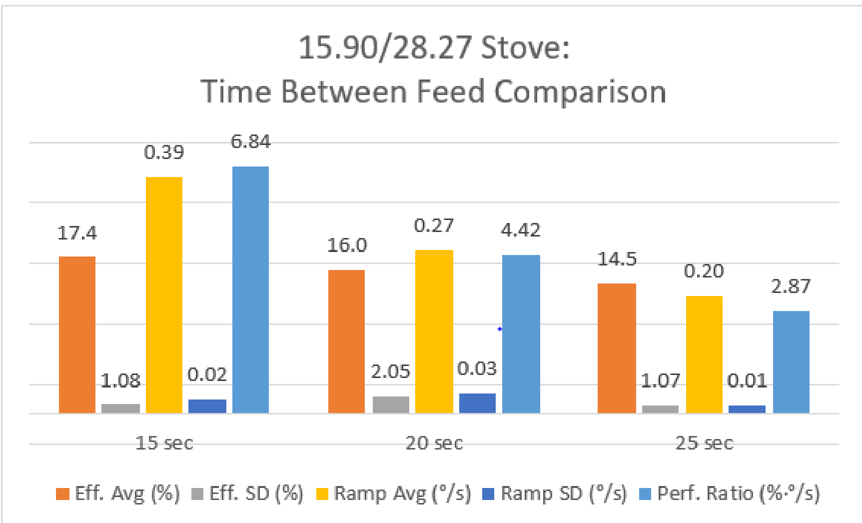
It is important to keep the inlet hole free from blockage to maintain a steady burn. The fire may need to be stoked occasionally as well to make sure that ash does not build up on the grate and prevent air flow. An overabundance of fuel can also choke out the fire and prevent air flow.

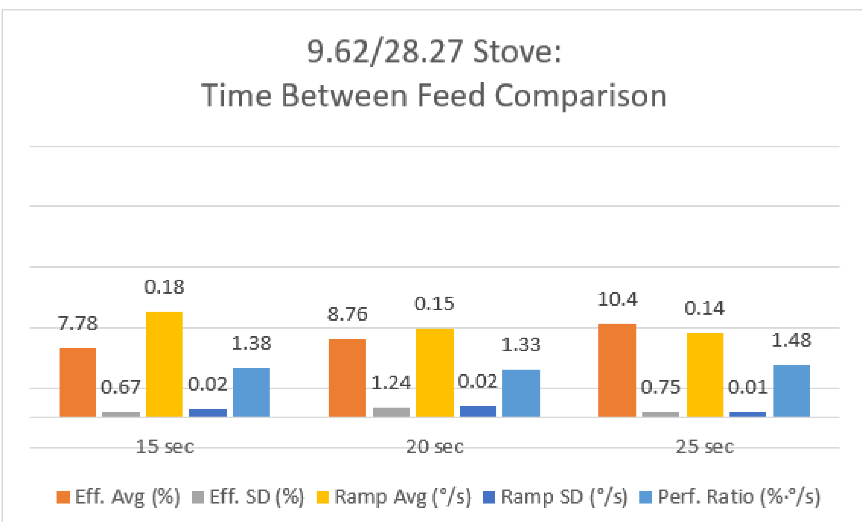
Conclusion

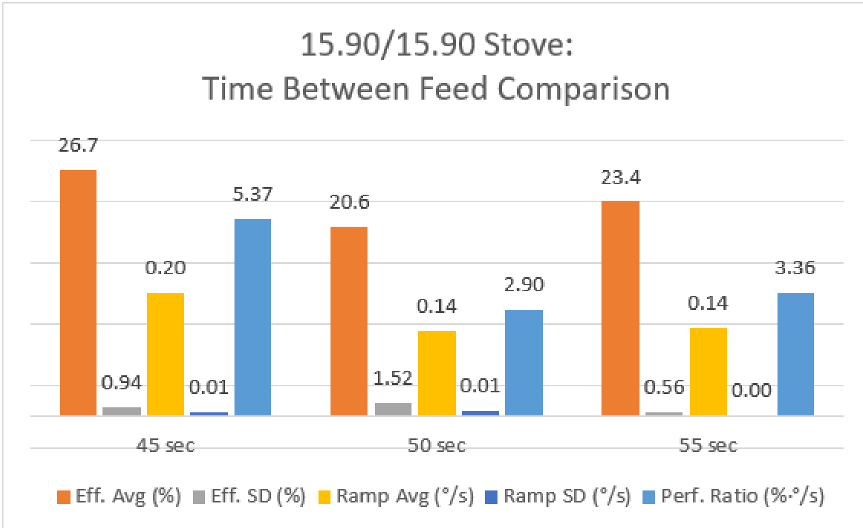
The depth of the stove is important to create a chimney and provide insulation for the burn chamber. As the stove heats up, the air rises and pulls more air from the inlet hole. This starts a process which continually pulls air faster until it creates a sound like a rocket, giving the rocket stove its name. The additional air helps to heat up the fire and smoke creating a more efficient and complete combustion of the fuel. The in-ground stove is an optimal solution to situations where materials are not available to build a formal rocket stove but a heating and cooking method is required.

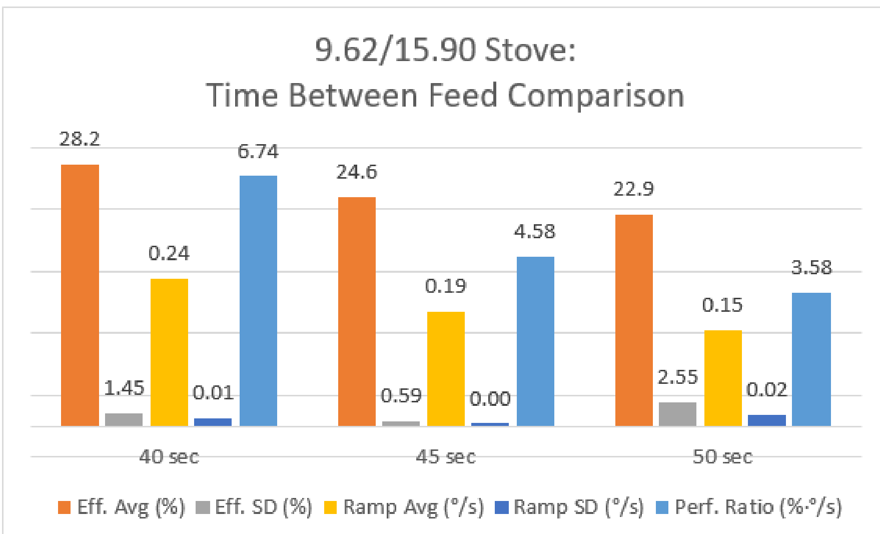
Appendix G Concrete Stove Feed Interval Comparison Graphs

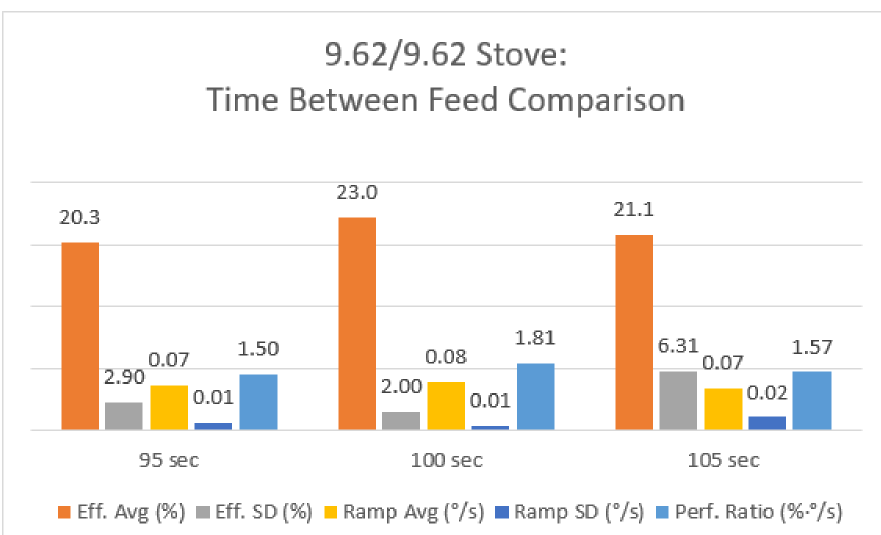
The graphs below were created to analyze and precisely approximate the optimum feed rate for each stove. Since each of the stoves had varying inlet to outlet ratios the fuel rates varied. The optimum fuel rates correspond with a time between feeds which is the amount in seconds between feeding the fire with a standardized size of wood. The optimum time between feeds were utilized in the inlet/outlet design of experiments as a constant variable. The graphs below display the averages of three replicates of three different time between feeds (fuel rate). The averages with the highest Ramp Avg (ramp rate of water temperature) are determined to be the optimum fuel rate because it demonstrates that the stove can burn the fuel at the rate that it is input, without overfeeding the stove. The Eff. Avg (efficiency average) and Perf. Ratio (performance ratio) are additional measurements taken from each test. It is important to note that these correspond with the ramp rate of water temperature. The SD (standard deviations) are additionally displayed in the graph to demonstrate that the data is precise.






15.90/15.90 Stove:
Time Between Feed Comparison
26.7
0.94
0.20
0.01
5.37
20.6
1.52
0.14
0.01
2.90
23.4
0.56
0.14
0.00
3.36
45 sec
50 sec
55 sec
Eff. Avg (%)
Eff. SD (%)
Ramp Avg (°/s)
Ramp SD (°/s)
Perf. Ratio (%·°/s)


9.62/15.90 Stove:
Time Between Feed Comparison
28.2
1.45
0.24
0.01
6.74
24.6
0.59
0.19
0.00
4.58
22.9
2.55
0.15
0.02
3.58
40 sec
45 sec
50 sec
Eff. Avg (%)
Eff. SD (%)
Ramp Avg (°/s)
Ramp SD (°/s)
Perf. Ratio (%·°/s)


9.62/9.62 Stove:
Time Between Feed Comparison
20.3
2.90
0.07
0.01
1.50
23.0
2.00
0.08
0.01
1.81
21.1
6.31
0.07
0.02
1.57
95 sec
100 sec
105 sec
Eff. Avg (%)
Eff. SD (%)
Ramp Avg (°/s)
Ramp SD (°/s)
Perf. Ratio (%·°/s)

Appendix H Gasification DOE 1 Test Plan

StdOrder	RunOrder	PtType	Air Outflow Height (in)	Air Outflow Area (in^2)
1	1	1	12.0	0.166
4	4	1	16.3	0.166
19	19	1	12.0	0.166
6	6	1	16.3	0.499
3	3	1	12.0	0.499
20	20	1	20.5	0.499
7	7	1	20.5	0.166
13	13	1	16.3	0.166
22	22	1	16.3	0.166
8	8	1	20.5	0.332
11	11	1	12.0	0.332
5	5	1	16.3	0.332
16	16	1	12.0	0.499
9	9	1	20.5	0.499
15	15	1	16.3	0.499
2	2	1	12.0	0.332
26	26	1	20.5	0.332
20	20	1	12.0	0.332
16	16	1	20.5	0.166
10	10	1	12.0	0.166
25	25	1	20.5	0.166
17	17	1	20.5	0.332
14	14	1	16.3	0.332
23	23	1	16.3	0.332
24	24	1	16.3	0.499
27	27	1	20.5	0.499
21	21	1	12.0	0.499
	Note:	.166 in^2 = 4 holes		
		.332 in^2 = 8 holes		
		.499 in^2 = 16.25 holes		

Appendix I Gasification DOE 2 Test Plan and Results

Parameters		Reptition	Ramp Rate (degC/s)	Efficiency %	Overal Performance (%*degC/s)
Outlet	Gasification Tube				
Open	Closed	1	0.1210	10.4100	1.2596
Open	Closed	2	0.1151	10.8900	1.2534
Open	Closed	3	0.1111	10.2800	1.1421
Open	Open	1	0.2367	20.36	4.8192
Open	Open	2	0.2333	20.07	4.6823
Open	Open	3	0.2139	18.40	3.9358
Closed	Open	1	0.1398	23.81	3.3286
Closed	Open	2	0.1128	23.76	2.6801
Closed	Open	3	0.1580	20.74	3.2769
Closed	Closed	1	0.1384	22.22	3.0752
Closed	Closed	2	0.1381	17.92	2.4748
Closed	Closed	3	0.0957	25.10	2.4021

Appendix J Gasification Carbon Monoxide DOE Test Plan

Parameters			Replicates
Stove Inlet	Gasification Pipe	Three Stone Fire	
Open	Closed	NA	1
Open	Closed	NA	2
Open	Closed	NA	3
Open	Open	NA	1
Open	Open	NA	2
Open	Open	NA	3
Closed	Closed	NA	1
Closed	Closed	NA	2
Closed	Closed	NA	3
NA	NA	High	1
NA	NA	Low	1

Appendix K Concrete Stove DOE Test Procedure

1. Stove warm up: Put between 4-10 pieces of wood in the base.
2. Light wood with propane torch (on low) by holding in inlet for 15 minutes. Turn off torch.
3. Add wood if run low on fuel during 15 minutes.
4. Continue to sustain fire for another 15 minutes by adding wood when necessary.
5. Check to make sure red hot coals are in stove. Use thermometer to check to see if outside of stove temp is at least 100℃.
6. Using a timer, begin dropping one piece of wood into the chimney at rate specified for test.
7. Fill pot with 1L of water with water at temperature around 40℃.
8. Place wire pot stand on stove. Place K-thermocouple at outlet and J-thermocouple in water.
9. After continuing constant feed rate for at least 5 minutes, place pot of water on stove and start program.
10. After 10 minutes of continuing constant feed rate stop program and export data to excel.
11. BE SURE TO COPY AND PASTE PERFORMANCE RATIO INTO THE DOE2 EXCEL FILE ON THE DESKTOP! Also, record this ratio in the notebook by the computer.
12. Remove pot and continue feed rate.
13. Repeat test for 2 more repetitions.
14. Ensure pot is thoroughly quenched before adding new water.
15. After testing is finished for the day. BE SURE TO TURN OFF VALVE ON PROPANE TANK BEHIND SHED.
16. SAVE NEW EXCEL FILES ONTO FLASH DRIVE JUST IN CASE.

Appendix L Gasification DOE 1 Test Procedure

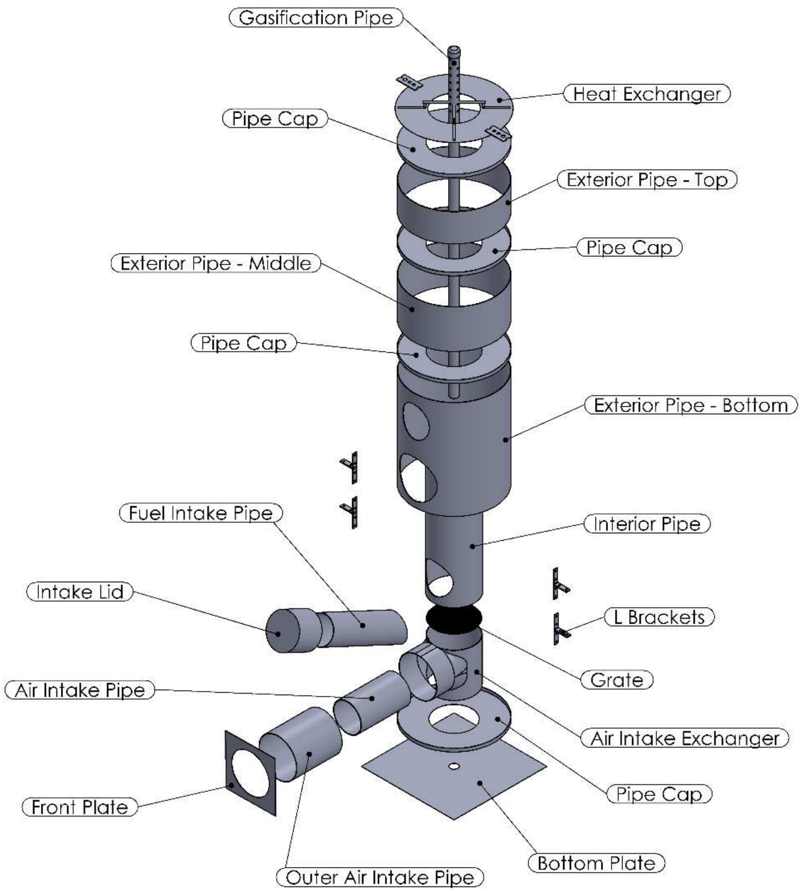
1. Add 10 blocks, 4 sticks (2 on each side of the gasification tube), and propane (4 min)
2. Stoke fire (2 min)
3. Stoke, remove propane (2 min)
4. Stoke, add 4 sticks (2 min)
5. Stoke (2 min)
6. Stoke (2 min)
7. Stoke, close inlet, add 4 sticks (5 min – collect data)
8. Stoke, open inlet, change height (2 min)
9. Stoke (2 min)
10. Stoke, add 4 sticks (2 min)
11. Stoke (2 min)
12. Stoke (2 min)
13. Stoke, close inlet, add 4 sticks (5 min – collect data)
14. Stoke, open inlet, change height (2 min)
15. Stoke (2 min)
16. Stoke, add 4 sticks (2 min)
17. Stoke (2 min)
18. Stoke (2 min)
19. Stoke, close inlet, add 4 sticks (5 min – collect data)
20. Remove gasification tube, change sleeve, cool stove (10 min)

Appendix M Gasification DOE 2 & CO DOE Testing Procedure

1. Add 10 blocks, 4 sticks (2 on each side of the gasification tube), and propane (4 min)
2. Stoke fire (2 min)
3. Stoke, remove propane (2 min)
4. Stoke, add 4 sticks (2 min)
5. Stoke (2min)
6. Stoke (2min)
7. Stoke, add 4 sticks (2 min)
8. Stoke (2min)
9. Stoke (2min)
10. Stoke, close inlet, add 4 sticks (5min – collect data)
11. Stoke, open inlet (2 min)
12. Stoke (2 min)
13. Stoke, add 4 sticks (2 min)
14. Stoke (2 min)
15. Stoke (2 min)
16. Stoke, close inlet, add 4 sticks (5min – collect data)
17. Stoke, open inlet (2 min)
18. Stoke (2 min)
19. Stoke, add 4 sticks (2 min)
20. Stoke (2 min)
21. Stoke (2 min)
22. Stoke, close inlet, add 4 sticks (5min – collect data)
23. Cool stove (10 min)

(Note: For CO monitor tests when stove inlet is opened and 3 stone fire is started, ignore close inlet steps)

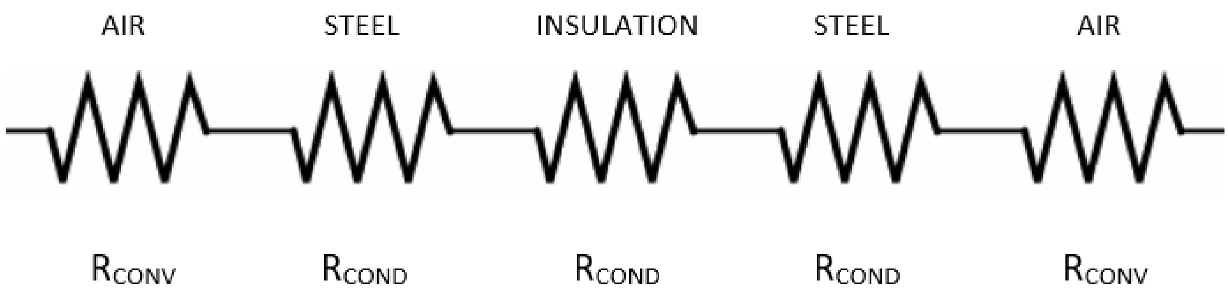
Appendix N Exploded View, Part Location, and Bill of Materials



Part Name	Material	QTY
Exterior Pipe - Bottom	12.875" Steel Pipe, 0.0625" Thickness	1
Exterior Pipe - Middle	12.875" Steel Pipe, 0.0625" Thickness	1
Exterior Pipe - Top	12.875" Steel Pipe, 0.0625" Thickness	1
Outer Air Intake	6" Steel Pipe, 0.0625" Thickness	1
Inner Air Intake	4.4375" Steel Pipe, 0.0875" Thickness	1
Fuel Intake	3.875" Steel Pipe, 0.0625" Thickness	1
Front Air Intake Plate	8" X 8" X 0.05" Steel Plate	1
Pipe Cap	0.03" Steel Plate	3
L Bracket	Steel L Bracket	4
Interior Burn Chamber	6.3125" Stainless Steel Pipe, 0.125" Thickness	1
Grate	Stainless Steel Grating	1
Air Intake Sweep		1
Bottom Cap	0.03" Steel Plate	1
Gasification Pipe	0.828125" Stainless Steel Pipe, 1.1875" Thickness	1
Pot Accessory		1
Gasification Plate	15" X 15" X 0.03" Steel Plate	1

Appendix O Insulation Wall Thickness Calculations

Purpose: Determine if or when the insulation wall thickness of cylindrical pipe becomes insignificant.



Insulation Values

Surface Area of Shapes = Constant

Length = Irrelevant

Thermal Conductivity = 0.2 W•m^{-1}•K^{-1}

Temperature$_{in}$ = 1273.15 K

Temperature$_{out}$ = 298.15 K

Surface Area$_{in}$ = 0.628319 m

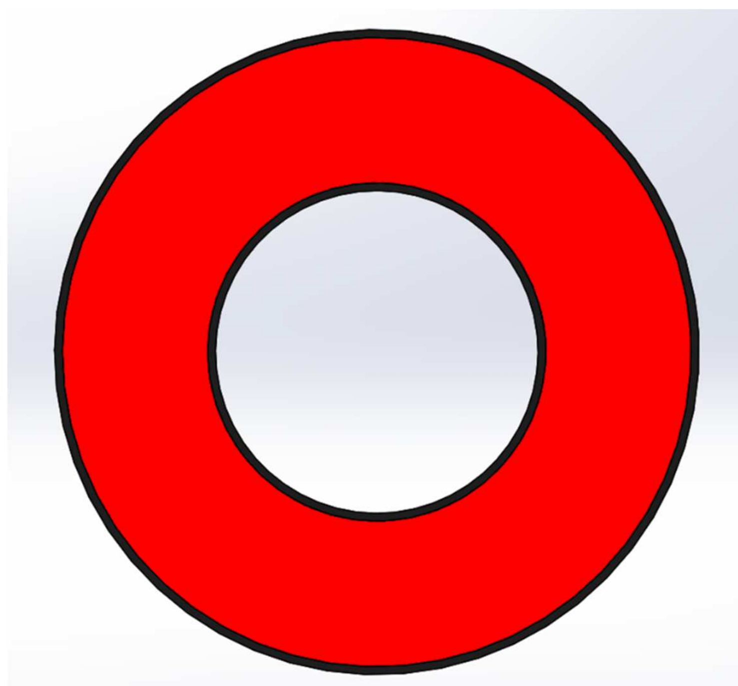
Surface Area$_{out}$ = 1.25664 m

Radius$_{in}$ = 0.1 m

Radius$_{out}$ = 0.2 m

Width$_{in}$ = 0.15708 m

Width$_{out}$ = 0.314159 m



$$R_{conv\ hot\ air} = \frac{1}{h_1 A_1} = \frac{1}{350\big(2\pi(0.2)\big)} = 0.002274\ \frac{mK}{W}$$

$$R_{cond\ steel} = \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi KL} = \frac{\ln\left(\frac{0.205}{0.2}\right)}{2\pi(27)} = 0.000146\frac{mK}{W}$$

$$R_{cond\ insulation} = \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi KL} = \frac{\ln\left(\frac{0.215}{0.205}\right)}{2\pi(2)} = 0.037901\,\frac{mK}{W}$$

$$R_{cond\ aluminum} = \frac{\ln\left(\frac{r_0}{r_i}\right)}{2\pi KL} = \frac{\ln\left(\frac{0.220}{0.215}\right)}{2\pi(167)} = 0.000022\,\frac{mK}{W}$$

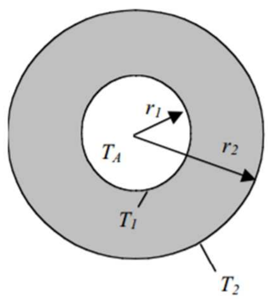
$$R_{conv\ hot\ air} = \frac{1}{h_2 A_4} = \frac{1}{30\big(2\pi(0.22)\big)} = 0.024114\,\frac{mK}{W}$$

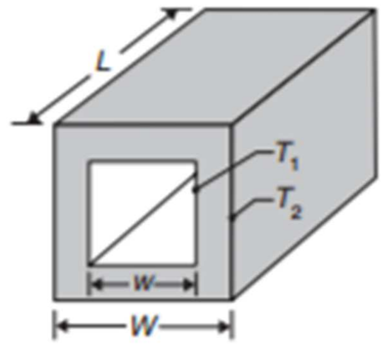
$$Q = \frac{\Delta T}{\sum R_T} = \frac{1273.15 - 298.15}{0.002274 + .000146 + 0.037901 + 0.000022 + 0.024114}$$

$$Q = 15126.4\,\frac{W}{m}$$

Appendix P Shape Calculations

Purpose: Determine which shape has the lowest heat loss by analyzing both the circular cylinder and square tube in 2D.





Surface Area of Shapes = Constant

Length = Irrelevant

Thermal Conductivity = 0.2 $W \cdot m^{-1} \cdot K^{-1}$

$Temperature_{in}$ = 1273.15 K

$Temperature_{out}$ = 298.15 K

Surface $Area_{in}$ = 0.628319 m

Surface $Area_{out}$ = 1.25664 m

$Radius_{in}$ = 0.1 m

$Radius_{out}$ = 0.2 m

$Width_{in}$ = 0.15708 m

$Width_{out}$ = 0.314159 m

$$q = kS\Delta T$$

$$S_{cyl} = \frac{2\pi L}{\ln(r_o/r_i)} \qquad S_{squ} = \frac{2\pi L}{0.93\, ln\left(\frac{w_o}{w_i}\right) - 0.05}$$

$$S_{cyl} = \frac{2\pi 1}{\ln\left(\frac{0.2}{0.1}\right)} = 9.06472 \qquad S_{squ} = \frac{2\pi 1}{0.93 \ln\left(\frac{0.314159}{0.15708}\right) - 0.05} = 10.5667$$

$$q_{cyl} = 0.2(9.06472)(1273.15 - 298.15) = 1767.62\,\frac{W}{m}$$

$$q_{squ} = 0.2(10.5667)(1273.15 - 298.15) = 2060.51\,\frac{W}{m}$$

$$q_{diff} = 292.89 \approx 14\%\, difference$$

Outside Radius of Al	Heat Loss (W/m)
0.110	18358.804
0.115	11075.941
0.120	8026.125
0.125	6348.642
0.130	5286.633
0.135	4553.406
0.140	4016.421
0.145	3605.956
0.150	3281.833
0.155	3019.266
0.160	2802.135
0.165	2619.503
0.170	2463.684
0.175	2329.122
0.180	2211.700
0.185	2108.301
0.190	2016.522
0.195	1934.481
0.200	1860.683
0.205	1793.926
0.210	1733.229
0.215	1677.789
0.220	1626.937
0.225	1580.115
0.230	1536.851
0.235	1496.746
0.240	1459.457
0.245	1424.691
0.250	1392.194
0.255	1361.743
0.260	1333.147

0.265	1306.237
0.270	1280.862
0.275	1256.892
0.280	1234.208
0.285	1212.707
0.290	1192.296
0.295	1172.891
0.300	1154.416
0.305	1136.805
0.310	1119.994
0.315	1103.930
0.320	1088.562
0.325	1073.843
0.330	1059.732
0.335	1046.189
0.340	1033.181
0.345	1020.675
0.350	1008.640
0.355	997.050
0.360	985.880
0.365	975.105
0.370	964.705
0.375	954.658
0.380	944.948
0.385	935.555
0.390	926.465
0.395	917.661
0.400	909.131

Appendix Q TEG Specs

TEC
SOLIDSTATE POWER GENERATORS

CARBON REDUCING TECHNOLOGY

MODULE TEG1-PB-12611-6.0

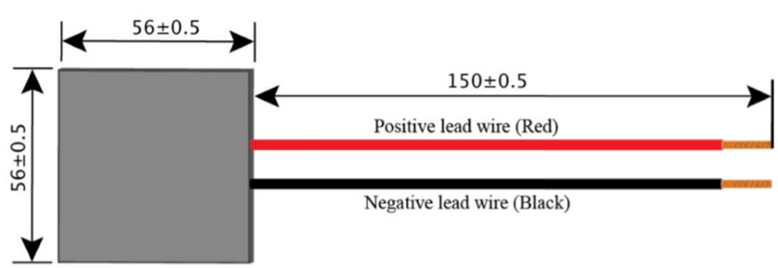
OPERATING PARAMETERS:

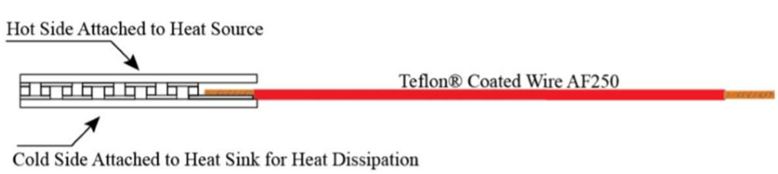
Seebeck Effect thermoelectric power modules are design with high temperature bonding materials that allow them to withstand temperatures of up to 360°C (680°F). As long as the module is placed into a system, whereby the hot side is at a higher temperature than the cold side, DC power will be produced. A unique new class of module is now available. Incorporating 2 optimized semi-conductors of N-type A material & P-type A material to form a **hybrid module** of superior performance & temperature stability. The TEG1-PB class of module is able to operate continuously in higher temperatures than traditional BiTe material only. The ceramic surfaces are equipped with graphite sheets, which displace the need for thermal grease. These novel modules work best in the 220 to 360C Temperature range and offer superior performance over 260C hot side, compared to standard BiTe modules.

Module Specifications

Hot Side Temperature (˚C)	350
Cold Side Temperature (˚C)	30
Open Circuit Voltage (V)	9.2
Matched Load Resistance (ohms)	0.97
Matched Load Output Voltage (V)	4.6
Matched Load Output Current (A)	4.7
Matched Load Output Power (W)	21.7
Heat Flow Across the Module (W)	≈310
Heat Flow Density (W cm^{-2})	≈9.88
AC Resistance (ohms) Measured under 27 ˚C @ 1000 Hz	0.42~0.52

Geometric Characteristics (Dimensions In Millimeters)

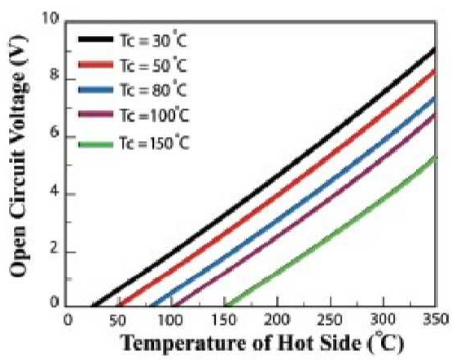




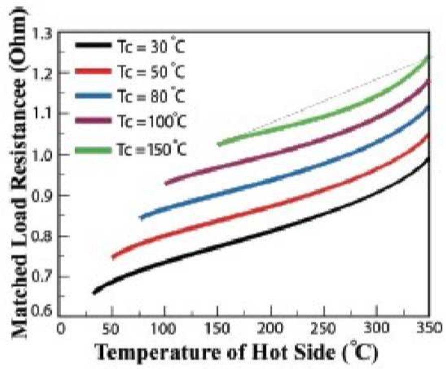
TEL: 905-751-1362 email: tecteg@rogers.com www.thermoelectric-generator.com

MODULE TEG1-PB-12611-6.0

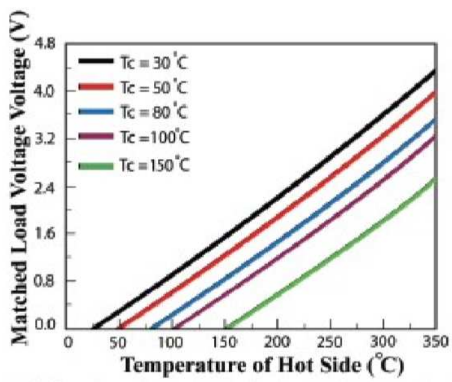
PERFORMANCE CURVES:



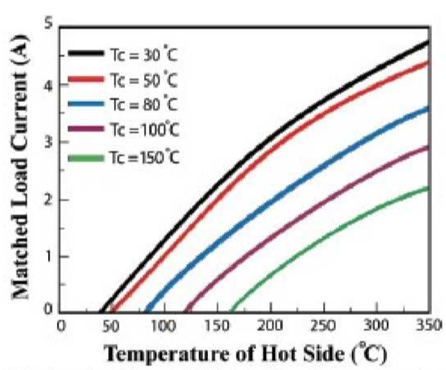
This chart shows open circuit voltage V_S T_h under various T_C .



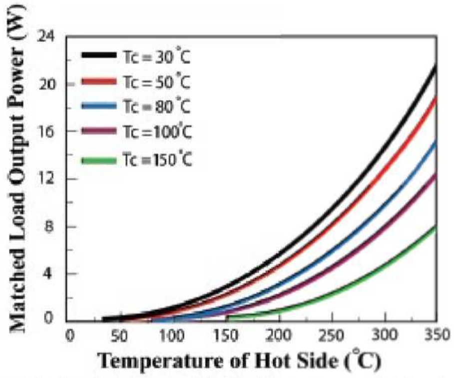
This graph shows open circuit voltage V_S T_h under various T_c .



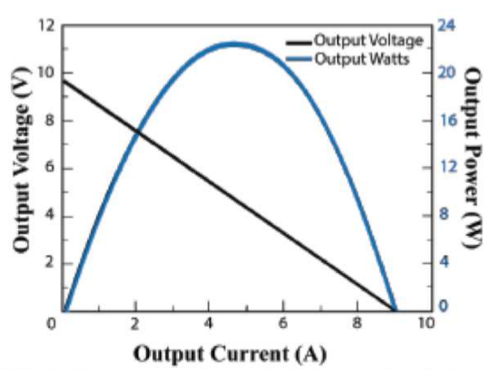
This chart shows the matched load voltage V_s T_h under various T_c.



This chart shows the matched load voltage V_S T_h under various T_c .



This chart shows the matched load output power V_S T_h under various T_c .



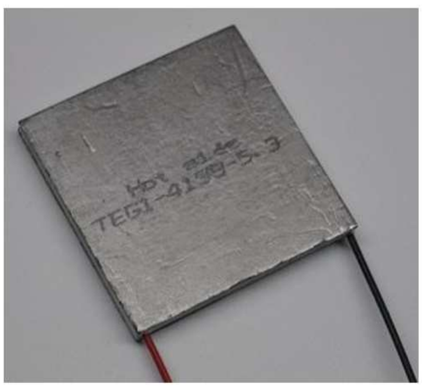
This chart shows output voltage and output power where V_S is output current under T_h = 300℃ and T_c = 30℃

CARBON REDUCING TECHNOLOGY

MODULE TEG1-4199-5.3

OPERATING PARAMETERS:

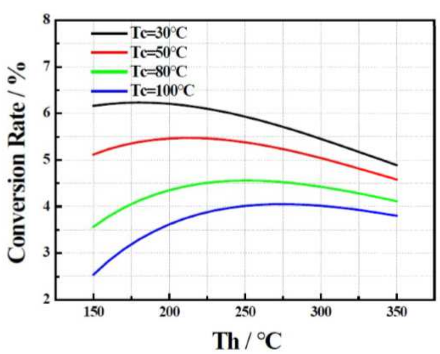
Seebeck Effect thermoelectric power modules are design with high temperature bonding materials that allow them to withstand temperatures of up to 320°C (608°F). As long as the module is placed into a system, whereby the hot side has a higher temperature than the cold side, DC power will be produced. The greater the DT (difference in temperature across the module the greater the power produced). These modules can be placed in parallel and series to produce a workable larger voltage. Each module is built with high temperature graphite sheets on both the hot & cold side, eliminating the need for thermal grease. The leads are connected to the cold side on the module in order to protect them from extreme temperatures.



Module Specifications

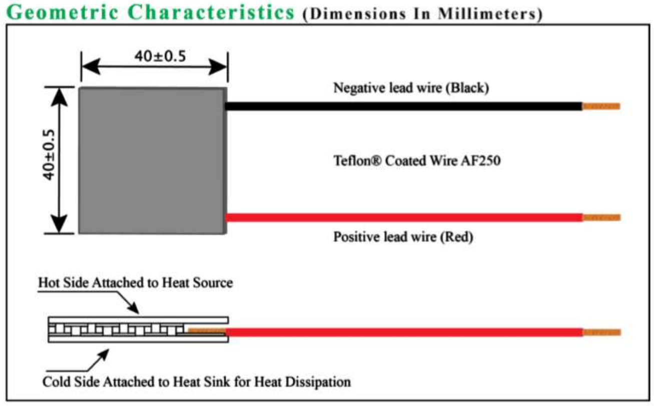
Hot Side Temperature (˚C)	300
Cold Side Temperature (˚C)	30
Open Circuit Voltage (V)	13.4
Matched Load Resistance (ohms)	5.7
Matched Load Output Voltage (V)	6.7
Matched Load Output Current (A)	1.12
Matched Load Output Power (W)	7.5
Heat Flow Across the Module (W)	≈152
Heat Flow Density (W cm^{-2})	≈9.5
AC Resistance (ohms) Measured under 27 ˚C @ 1000 Hz	3.3~4.2

Conversion Rate of the modules Vs Th under various Tc



Noted: Conversion rate = Matched load output power/Heat flow through the module

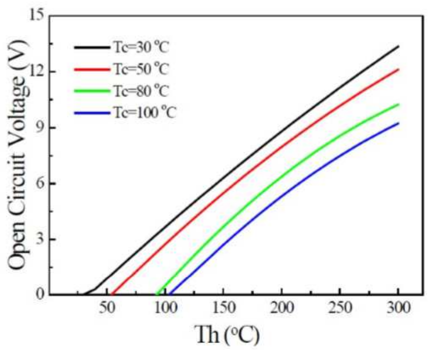
Geometric Characteristics (Dimensions In Millimeters)



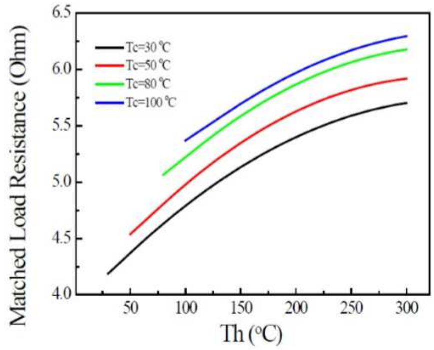
TEL: 905-751-1362 **email: tecteg@rogers.com** **www.thermoelectric-generator.com**

MODULE TEG1-4199-5.3

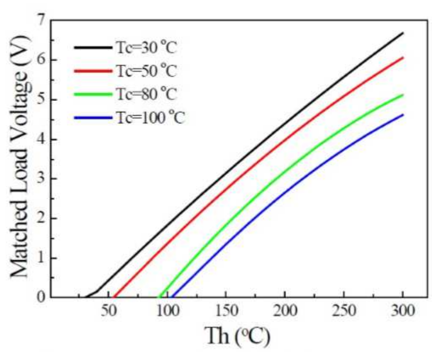
PERFORMANCE CURVES:



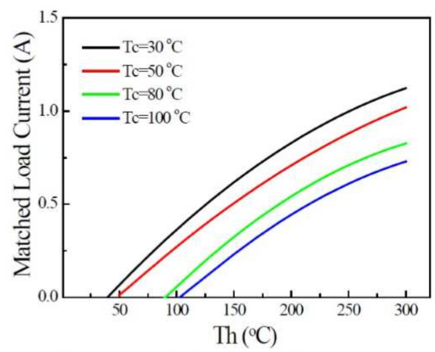
The chart for open circuit voltage Vs T_h under various T_c



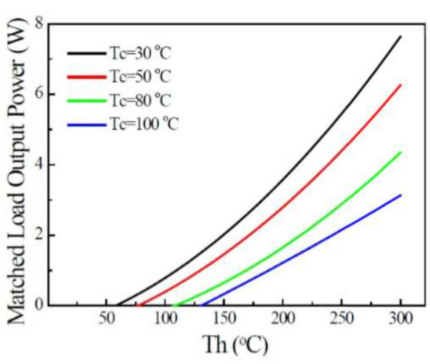
The chart for matched load resistance Vs T_h under various T_c



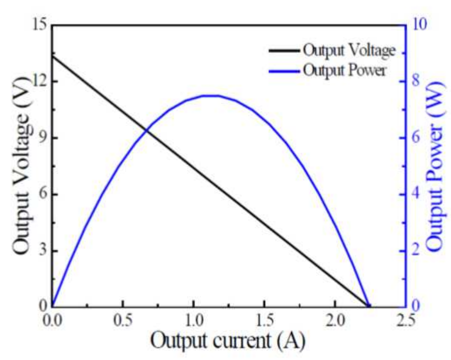
The chart for matched load voltage Vs T_h under various T_c



The chart for matched load current Vs T_h under various T_c



The chart for matched load output power Vs T_h under various T_c



The chart for output voltage and output power Vs output current under T_h=300 °C and T_c=30 °C

Appendix R IPowerTower™ Specs

Introducing the IPowertower™ fully integrated TEG Charging SYSTEM
(all you add is water and fuel)

CLICK TO LEARN MORE

Select Language

Powered by Google Translate

1-905-751-1362

tecteg@rogers.co

Tecteg Power Generator | About Us | What's News
Thermoelectric Power Products | Store | Compare TEG Modules | Contact Us
Testimonials

IPOWERTOWER™ Trangia Tablet Battery Charging

Home / IPOWERTOWER™ Trangia Tablet Battery Charging

Trangia Burner offers superior power output for the Thermoelectric 5v , 12V TEG Generator Introducing the IPowertower™ fully integrated TEG Charging Generator using a Trangia Burner (all you add is water and fuel) See its power!

Recent Posts

- TEG POWER Gen III (P.O.W.E.R) has been installed and is being commissioned at the corporate head office of PIZZA PIZZA LTD.
- Thermal Electronics Corp. reported today that their TEG POWER Gen III has been electrically approved for installation.
- Thermal Electronics Corp. product announcement – 80W TEG Interface System

IPowertower™ ! The IPOWERTOWER $149.99 plus 24.00 shipping in North America Only! Email for overseas shipping rates! The new standard in cell phone, tablet charging with dual battery charging using a single 3oz can of fuel for 5W, Triangia ~7W or more, propane ~7W or more. Fuel selection can vary from Sterno Gel to alcohol based fuels and propane. A Trangia Burner or propane offers superior power output based on higher heat Flux content for tablet charging. Dung, Wood Chips can also be used to fuel the IPowertower™ a patent pending design, culminating from 25 years of thermoelectric experience, with no moving parts.

Exceptional power output with the ability to supercharge you cell phone, while also charging at the same time any size battery up to 12V or run LED lights.

The TEG Generator comes with a battery MPP Voltage charge controller with dual outputs delivering a 98% conversion efficiency. A 5V USB charging port, Rated for 5W coupled with a 4 port screw terminal that can be wired simultaneously to charge any battery from 1.2v up to 12v with no settings required. It is all done automatically and will never overcharge your battery " Smart Charger". The TEG Heater Generator can also directly power LED lighting in Emergency situations when the grid goes down. Emergency back-up TEG generator charging system. The IPowertower™ is portable and easy to use, Can be used as an emergency heater in a well ventilated room . We have a patented "Power Booster System"™ uniquely designed to power boost the output during operation.

With today's larger screen smartphones and rapid charging power requirements especially the IPhone 6 & IPAD MINI the IPowertower™ is uniquely designed to charge these device rapidly as quickly! As quickly as a wall charger with a USB Turbo charger option.

The TEG *IPowertower*™ Generator heater system will also be available in 4 unique colors. Silver on Black, Blue on Black, Black on Black and Green on Black.

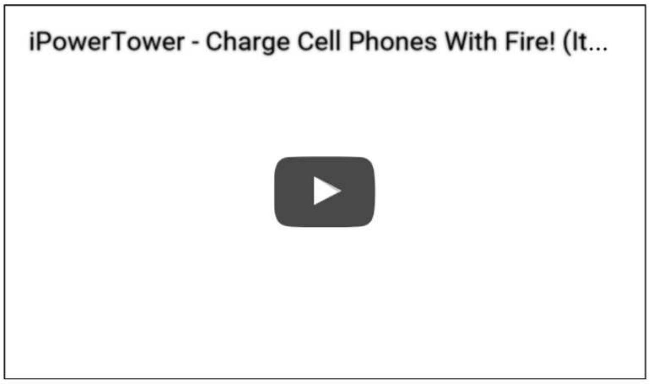
- Best TEG module design for Micro Scavenging Heat from the Human Body!
- iPower Smartphone TEG Generator Charging System

Recent Comments

- tecteg on TEC signs Agreement with TKB Ind. to develop TEG SMART Battery Charging Controller

Archives

- February 2017
- January 2017
- October 2016
- November 2015
- October 2015
- March 2015
- December 2014
- October 2014
- August 2014
- March 2014
- October 2013
- March 2011



Features:

- No moving parts!
- Dual output 5V USB and a terminal for charging any battery up to 12V or running LED lights!
- Ability to charge a Tablet!
- Available in 4 colors!
- Portable!
- Ability to Charge indoors using the proper fuel! Alcohol based fuels ONLY!
- Easy to fill and equally easy to empty?
- Attractive look!
- Extremely safe to use!
- Easy to set-up and operate!
- Security features!
- Operates using multiple fuels!
- "Power Booster System"™

Specifications:

- Rated 10 watts
- 1.5 liters water cold side chamber
- 80mm clearance for up to 5oz can.
- Easy empty feature
- 6 lbs gross weight

To pre-order, please fill the form below and we will advise when its ready.
"There is "No obligation to purchase!"

Name	Email	Phone

- February 2011
- January 2011
- August 2010
- July 2010
- May 2010
- April 2010
- January 2007
- January 2004

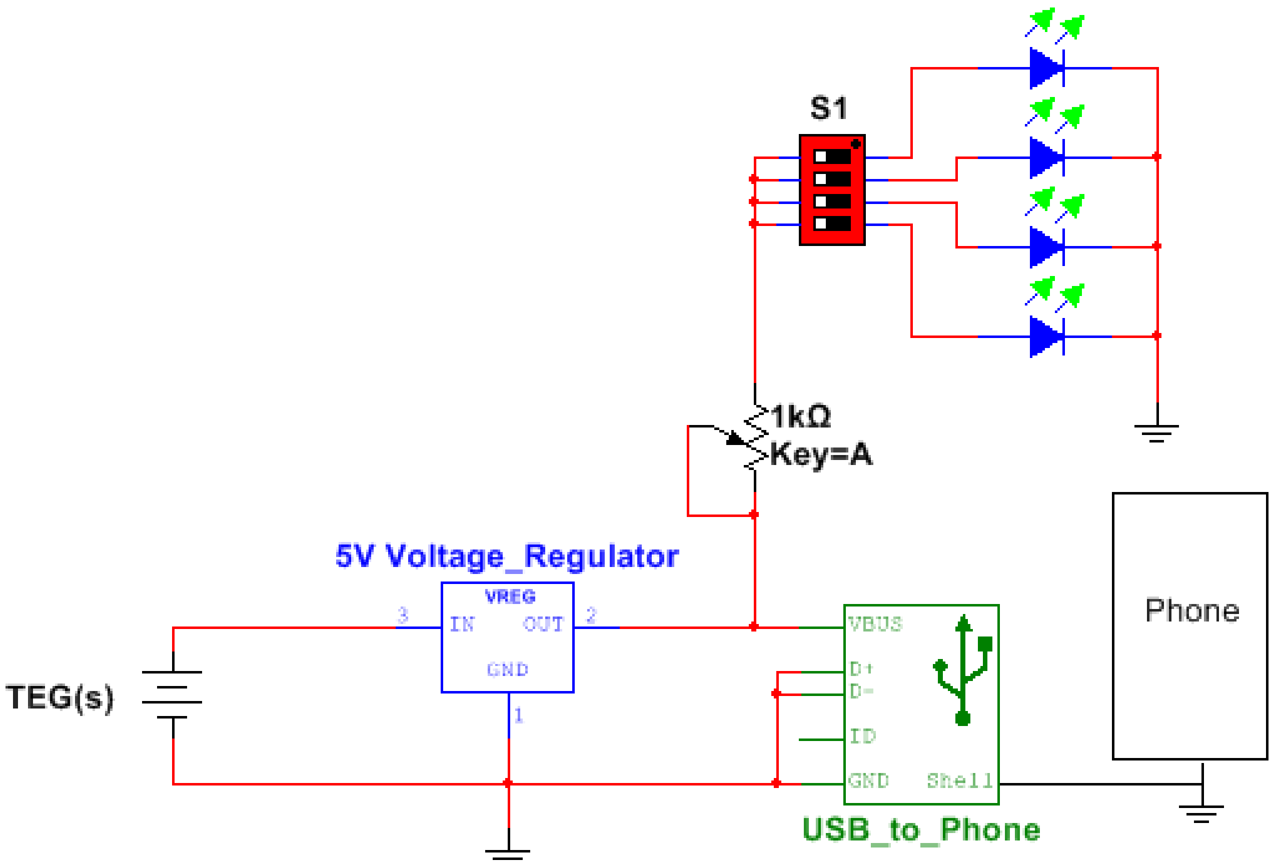
Categories

- Blog
- Footer Posts
- What's News

Meta

- Log in
- Entries RSS
- Comments RSS
- WordPress.org

Appendix S Circuit Schematic (TEG Power Regulator)



Appendix T Rutland Cement MSDS Sheets

Material Safety Data Sheet
May be used to comply with
OSHA's Hazard Communication Standard,
29 CFR 1910.1200 Standard must be
consulted for specific requirements.

U.S. DEPARTMENT of Labor
Occupational Safety and Health Administration
(Non-Mandatory Form)
Form Approved
OMB No. 1218-0072

IDENTITY *(As Used on Label and List)*
Code 63, 63B, 63BT, 63G
Fireplace Mortar

Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

Section I

Manufacturer's Name: RUTLAND PRODUCTS	Emergency Telephone Number: CHEMTREC 800-424-9300
Address *(Number, Street, City, State, and Zip Code)*: 7 CRAB TREE ROAD, JACKSONVILLE, IL 62650	Telephone Number Information: 217-245-7963
	Date Prepared: May 1990 — Date Revised: Nov., 04
	Signature of Preparer *(optional)*:

Section II - Hazardous Ingredients/Identity Information

Chemical Identity	CAS #	OSHA PEL	ACGIH TLV	Other Limits Recommended	% *(optional)*
Sodium Hydroxide	01310-73-2	2mg/m³	2mg/m³		
Sodium Silicate	01344-09-8	None Established		5mg/m³	
Calcium Metasilicate	13983-17-0	None Assigned			
Hydrous Aluminum Silicate	01332-58-7	N/A	N/A		
Silica, quartz	14808-60-7	10mg/m3/ %SiO+2	0.1mg/m3	Respirable*	

*The silica in this product is totally encapsulated and thus present no inhalation danger to the user.

HMIS Rating - Health: 2 Flammability: 0 Reactivity: 0

Section III - Physical/Chemical Characteristics

Boiling Point	N/A	Specific Gravity (H_2O = 1)	1.8
Vapor Pressure (mm Hg)	N/A	Melting Point	N/A
Vapor Density (Air = 1)	N/A	Evaporation Rate (Butyl Acetate = 1)	N/A

Solubility in Water
Product is a mixture, partly soluble in water until heat cured.

Appearance and Odor
Colored, gunnable mortar. May be black, buff, gray. No odor.

Section IV - Fire and Explosion Hazard Data

Flash Point (Method Used)	Flammable Limits	LEL	UEL
N/A	N/A	N/A	N/A

Extinguishing Media
N/A Will not burn.

Special Fire Fighting Procedures
N/A

Unusual Fire and Explosion Hazards
N/A

The information presented herein is based either on data or opinion. Such data is, to the best of our knowledge, true and accurate. Such opinion is believed to be expert, and therefore generally reliable, but in some instances there are conflicts in expert opinion and in these instances we have relied on the opinion which, in our best judgment, appeared the most reasonable. All information herein is presented without guarantee or warranty and Rutland Products disclaims any liability incurred from the use thereof.

Section V - Reactivity Data

Stability			Conditions to Avoid
	Unstable		N/A
	Stable	X	

Incompatibility *(Materials to Avoid)*
Contact with acid will cause evolution of heat.

Hazardous Decomposition or Byproducts

None

Hazardous Polymerization	May Occur		Conditions to Avoid
	Will Not Occur	X	None

Section VI - Health Hazard Data

Route(s) of Entry — Inhalation? No — Skin? Yes — Ingestion? Yes

Health Hazards *(Acute and Chronic)*

Skin: direct contact with skin for prolonged period will cause reddening.
Eyes: direct contact with eyes will cause watering and irritation.
Prolonged contact with eyes will cause alkaline burns.
Ingestion: may cause gastrointestinal upset.

Carcinogenicity — NTP? No — IARC Monographs? OSHA Regulated? No

Respirable silica from occupational sources is listed by IARC as a human carcinogen.

Signs and Symptoms of Exposure

See health hazards.

Medical Conditions Generally Aggravated by Exposure

Skin diseases may be aggravated by contact from product.

Emergency and First Aid Procedures

Skin: wash off with soap and water.
Eyes: wash with water at least 15 minutes. Consult an eye doctor.
Ingestion: consult a physician.

Section VII - Precautions for Safe Handling and Use

Steps to Be Taken in Case Material Is Released or Spilled

Scoop up.

Waste Disposal Method

Local landfill in accordance with local, state, and federal regulations.

Precautions to Be Taken in Handling and Storing

Keep covered when not in use. Keep out of reach of children.

Other Precautions

Rotate stock.

Section VIII - Control Measures

Respiratory Protection *(Specify Type)*

None needed.

Ventilation	Local Exhaust	Special
	Sufficient to carry away water vapor as product dries.	None
	Mechanical *(General)*	Other
	None	None

Protective Gloves	Eye Protection
Wear rubber gloves.	Wear safety glasses or splash goggles.

Other Protective Clothing or Equipment

Wear rubber apron.

Work/Hygienic Practices

Good housekeeping practices.

NAME OF PRODUCT: Rutland Fireplace Mortar

This product contains the following chemicals subject to the reporting requirements of Section 313 of SARA Title III.

CAS Number	Chemical Name	%,WT
01310-73-2	Sodium Hydroxide	1.2

NAME OF PRODUCT: Rutland Fireplace Mortar

This product contains the following chemicals subject to the reporting requirements of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA). These Chemicals are also subject to reporting under Section

304 of Title III, SARA.

CAS Number	Chemical Name	%,WT	Reportable Quantity
01310-73-2	Sodium Hydroxide	1.2	1,000 lbs.

Material Safety Data Sheet – Perlite

-----------------------------**I. Product Identification** ------------------------------

Trade Name (as labeled)	Supreme Perlite (Expanded)
Manufacturers Name	Supreme Perlite Company
Website & Email:	www.perlite.com info@perlite.com
Address:	4600 N. Suttle Rd. Portland, OR 97217
Phone Number:	503-286-4333
Date Revised:	02/24/2004

------------------------------**II. Product Ingredients**--------------------------------

Ingredient Name	CAS Number	%	PEL	TLV(total)
Perlite	93763-70-3	100	15 mg/M3	10mg/M3

A mineral composed of sodium potassium aluminum silicate of variable composition.

Perlite is considered a nuisance dust (also called "Particulates Not Otherwise Classified (PNOC) by ACGIH).

Alpha-Cristobalite & Tridymite:	Less than 0.1%
Alpha Quartz:	0.01 to 0.05%

-----------------------------**III. Physical Properties**--------------------------------

Vapor Density (air=1)	NA	**Melting point or range. °F**	2000+
Specific Gravity	2.35	**Boiling point or range. °F**	N/A
Solubility in Water	<1%	**Evaporation rate (butyl acetate = 1)**	N/A
Vapor Pressure (mmHg @ 20°C)	N/A		

Appearance and odor: White to off white granules, no odor.

HOW TO DETECT THIS SUBSTANCE (warning properties of substance as a gas, vapor, dust or mist)

Visual only (dust). No gas, vapors, or mist emitted.

------------------------------IV. Fire and Explosion--------------------------------

Flash Point, °F (give method) Perlite is a fully oxidized, non-flammable mineral. It is noncombustible and non-flammable.

Auto ignition temp., °F N/A

Flammable limits in air, Vol. % N/A lower (LEL) N/A upper (UEL) N/A

Fire extinguishing materials: N/A

_____water spray _____ carbon dioxide _____other

_____foam _____dry chemical

Special fire fighting procedures: N/A

Usual fire & explosion hazards: N/A

---------------------------V. Health Hazard Information-------------------------

SYMPTOMS OF EXPOSURE for each potential route of exposure

Inhaled: Coughing

Contact with skin or eyes: Possible eye irritation from dust particles; wear eye protection.

Absorbed through skin: N/A

Swallowed: N/A

HEALTH EFFECTS OR RISKS FROM EXPOSURE.

Acute: None

Chronic: Excessive inhalation over long period may cause harmful irritation; use mask suitable for nuisance dust.

Target Organ: None

FIRST AID: EMERGENCY PROCEDURES

Eye Contact:	Attempt to wash out with clear water; if unable, have particle removed by doctor.
Skin Contact:	None
Inhaled:	Remove affected individual from dusty area to area with clean air.
Swallowed:	None

SUSPECTED CANCER AGENT?

__X__ No: This product's ingredients are not found in below lists.

YES: ____Federal OSHA _____NTP _____IARC

MEDICAL CONDITIONS AGGREVATED BY EXPOSURE

Any respiratory illnesses, which a nuisance dust may aggravate.

-------------------------------VI Reactivity Data-------------------------------------

Stability:	**__X__Stable** _____Unstable
Incompatibility:	Hydrofluoric Acid
Hazardous Polymerization:	_____May occur **__X__Will not occur**
Conditions to avoid:	None in designed use.
Hazardous Decomposition Products:	May react with hydrofluoric acid form toxic gas.

------------------------VII. Spill, Leak & Disposal Procedures------------------

Spill response procedures (include employee protection measures):

Vacuum clean or sweep material; Use respirators suitable for nuisance dust & eye protection.

Preparing wastes for disposal (container types, neutralization, etc.):

Dispose in bulk or containers according to local dump requirements. No special treatment required.

NOTE: Dispose of all wastes in accordance with federal, state and local regulations.

---------------------VIII. SPECIAL HANDLING INFORMATION------------

Ventilation and engineering controls:

Maintain dust level below TLV.

Respiratory protection (type):

Masks suitable for nuisance dust.

Eye protection (type):

Protective goggles.

Gloves (specify material):

Not required.

Work practices, hygienic practices:

Use good housekeeping to avoid transient dust.

Other handling and storage requirements:

Use good housekeeping to avoid transient dust.

Protective measures during maintenance of contaminated equipment:

No special equipment, other than respirators and goggles.

As of the date of this document, the foregoing information is believed to be accurate and is provided in good faith to comply with applicable federal and state laws. However, no warranty or representation with respect to such information is intended or given, and it is the responsibility of the user to comply with all applicable federal, state and local laws and regulations

Appendix V JB Weld MSDS Sheets

SAFETY DATA SHEET

Issuing Date 27-Oct-2014 **Revision Date** 15-Oct-2014 **Revision Number** 2

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product SDS Name **Epoxy Putty Stick – High Heat**

J-B Weld FG SKU Part Numbers Covered

8297, 8297F

J-B Weld Product Names Covered

HighHeat™ (all sizes)

J-B Weld Product Type

Epoxy Putty Stick

Recommended use of the chemical and restrictions on use

Recommended Use Adhesive & Repair

Uses advised against No information available

Details of the supplier of the safety data sheet

Supplier Name J-B WELD COMPANY, LLC
Supplier Address 1130 COMO ST
SULPHUR SPRINGS, TX 75482
USA

Emergency Telephone Numbers Transportation Emergencies: Chemtrec (24 hour transportation emergency response info): 800-424-9300 or 703-527-3887

Poison/Medical Emergencies: Poison Control Centers (24 hour emergency poison / medical response info): 800-222-1222

Supplier Email info@jbweld.com

Supplier Phone Number 903-885-7696

2. HAZARDS IDENTIFICATION

OSHA/HCS status This material is considered hazardous by the OSHA Hazard Communication Standard (29-CFR 1910.1200).

Classification of the substance or mixture	SKIN SENSITIZATION – Category 1

GHS label elements

Hazard pictograms

Signal word	Warning!
Hazard statements	Causes skin and eye irritation. May cause an allergic skin reaction.

Precautionary statements

General	Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand.
Prevention	Wear protective gloves. Wear eye or face protection. Avoid breathing dust. Wash hands thoroughly after handling. Contaminated work clothing should not be allowed out of the workplace.
Response	IF ON SKIN: Wash with plenty of soap and water. Take off contaminated clothing. Wash contaminated clothing before reuse. If skin irritation or rash occurs: Get medical attention. IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. If eye irritation persists: Get medical attention.
Storage	Not applicable.
Disposal	Dispose of contents and container in accordance with all local, regional, national and international regulations.
Hazards not otherwise classified	None known.

3. COMPOSITION/INFORMATION ON INGREDIENTS

Substance/mixture Mixture

Ingredient name	% by weight	CAS number
Cristobalite	10-30	14464-46-1
crystalline silica non-respirable	10-30	14808-60-7

Canada

Name	CAS number	%
Talc, not containing asbestiform fibres	14807-96-6	10-30
Cristobalite	14464-46-1	10-30
glass, oxide, chemicals	65997-17-3	10-30
crystalline silica non-respirable	14808-60-7	10-30
3,6-diazaoctanethylenediamin	112-24-3	0.1-1

Occupational exposure limits, if available, are listed in Section 8.

4. FIRST AID MEASURES

Description of necessary first aid measure

Inhalation	Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is regular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.
Skin contact	Wash with plenty of soap and water. Remove contaminated clothing and shoes. Wash contaminated clothing thoroughly with water before removing it, or wear gloves. Continue to rinse for at least 10 minutes. Get medical attention. In the event of any complaints or symptoms, avoid further exposure. Wash clothing before reuse. Clean shoes thoroughly before reuse.
Eye contact	Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.
Ingestion	Wash out mouth with water. Remove dentures if any. Remove victim to fresh air and keep at rest in a position comfortable for breathing. If material has been swallowed and the exposed person is conscious, give small quantities of water to drink. Stop if the exposed person feels sick as vomiting may be dangerous. Do not induce vomiting unless directed to do so by medical personnel. If vomiting occurs, the head should be kept low so that vomit does not enter the lungs. Get medical attention if adverse health effects persist or are severe. Never give anything by mouth to an unconscious person. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Inhalation	Exposure to decomposition products may cause a health hazard. Serious effects may be delayed following exposure.
Skin contact	May cause an allergic skin reaction.
Eye contact	No known significant effects or critical hazards.
Ingestion	No known significant effects or critical hazards.

Over-exposure signs/symptoms

Inhalation	No specific data.
Skin contact	Adverse symptoms may include the following: irritation redness
Eye contact	No specific data

Ingestion	No specific data

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician	In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.
Specific treatments	No specific treatment.

See toxicological information (Section 11)

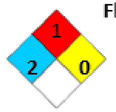
5. FIRE-FIGHTING MEASURES

Extinguishing media

Suitable extinguishing media	Use an extinguishing agent suitable for the surrounding fire.
Unsuitable extinguishing media	None known.
Specific hazards arising from the chemical	No specific fire or explosion hazard.

National Fire Protection Associationg (U.S.A.)

Health



Flammability

Instability/Reactivity

Special

Hazardous thermal decomposition products	Decomposition products may include the following materials: Carbon dioxide Carbon monoxide Nitrogen oxides Halogenated compounds Metal oxide/oxides
Special protective actions for fire-fighters	Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training.
Special protective equipment for fire-fighters	Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in a positive pressure mode.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Personal Precautions	Avoid contact with skin, eyes or clothing. Ensure adequate ventilation. Use personal protective equipment as required. Avoid generation of dust. Do not breathe dust. Evacuate personnel to safe areas.
Other Information	Refer to protective measures listed in Sections 7 and 8.

Environmental Precautions

Environmental Precautions	Refer to protective measures listed in Sections 7 and 8. Prevent further leakage or spillage if safe to do so.

Methods and material for containment and cleaning up

Methods for Containment	Prevent further leakage or spillage if safe to do so.
Methods for cleaning up	Pick up and transfer to properly labeled containers.

7. HANDLING AND STORAGE

Conditions for safe storage, including any incompatibilities	Do not store above the following temperature: 35°C (95°F). Store in accordance with local regulations. Store in original container protected from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10) and food and drink. Keep container tightly closed and sealed until ready for use. Containers that have been opened must be carefully resealed and kept upright to prevent leakage. Do not store in unlabeled containers. Use appropriate containment to avoid environmental contamination.

Precautions for safe handling

Protective measure	Put on appropriate personal protective equipment (see Section 8). Persons with a history of skin sensitization problems should not be employed in any process in which this product is used. Do not get in eyes or on skin or clothing. Do not ingest. Keep in the original container or an approved alternative made from a compatible material, kept tightly closed when not in use. Empty containers retain product residue and can be hazardous. Do not reuse container.
Advice on general occupational hygiene	Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measure.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Occupational exposure limits

Ingredient name	CAS #	Exposure limits
cristobalite	14464-46-1	**OSHA PEL Z3 (United States, 9/2005). Notes: 1/2[250/(%SiO2+5)]** TWA: 250 MPPCF / 2 x (%SiO2+5) 8 hours. Form: Respirable **OSHA PEL Z3 (United States, 9/2005). Notes: 1/2[10/(%SiO2+2)]** TWA: 10 MG/M3 / 2 x (%SiO2+2) 8 hours. Form: Respirable **OSHA PEL 1989 (United States, 3/1989).** TWA: 0.05 mg/m³, (as quartz) 8 hours. Form: Respirable dust **ACGIH TLV (United States, 3/2012).** TWA: 0.025 mg/m³ 8 hours. Form: Respirable fraction **NIOSH REL (United States, 1/2013).** TWA: 0.05 mg/m³ 10 hours. Form: respirable dust **OSHA PEL Z3 (United States, 9/2005). Notes: 1/2[30/(%SiO2+2)]** TWA: 30 MG/M3 / 2 x (%SiO2+2) 8 hours. Form: Total dust.
crystalline silica non-respirable	14808-60-7	**OSHA PEL Z3 (United States, 9/2005). Notes: 250/(%SiO2+5)** TWA: 250 MPPCF / (%SiO2+5) 8 hours. Form: Respirable **OSHA PEL Z3 (United States, 9/2005). Notes: 10/(SiO2+2)** TWA: 10 MG/M3 / (%SiO2+2) 8 hours. Form: Respirable **ACGIH TLV (United States, 3/2012).** TWA: 0.025 mg/m³ 8 hours. Form: Respirable fraction **NIOSH REL (United States, 1/2013).** TWA: 0.05 mg/m³ 10 hours. Form: respirable dust **OSHA PEL Z3 (United States, 9/2005). Notes: 30/(%SiO2+2)** TWA: 30 MG/M3 / (%SiO2+2) 8 hours. Form: Total dust.

Canada

Occupational exposure limits	TWA (8 hours)	STEL (15 mins)	Ceiling	

Ingredient	List name	ppm	mg/ m³	Other	ppm	mg/ m³	Other	ppm	mg/ m³	Other	Notations
crystalline silica non-respirable	US ACGIH 3/2012	-	0.025	-	-	-	-	-	-	-	[a]
	BC 4/2012	-	0.025	-	-	-	-	-	-	-	[b]
	ON 1/2013	-	0.1	-	-	-	-	-	-	-	[c]
	QC 12/2012	-	0.1	-	-	-	-	-	-	-	[d]
cristobalite	US ACGIH 3/2012	-	0.025	-	-	-	-	-	-	-	[a]
	AB 4/2009	-	0.025	-	-	-	-	-	-	-	[e]
	BC 4/2012	-	0.025	-	-	-	-	-	-	-	[b]
	ON 1/2013	-	0.05	-	-	-	-	-	-	-	[c]
	QC 12/2012	-	0.05	-	-	-	-	-	-	-	[d]
glass, oxide, chemicals	US ACGIH 3/2012	-	5	-	-	-	-	-	-	-	[f]
	US ACGIH 3/2012	-	-	1 f/cc	-	-	-	-	-	-	[g]
	AB 4/2009	-	5	1 f/cc	-	-	-	-	-	-	[h]
		-	5	-	-	-	-	-	-	-	[i]
	BC 4/2012	-	5	-	-	-	-	-	-	-	[j]
		-	-	1 f/cc	-	-	-	-	-	-	
	ON 1/2013	-	10	-	-	-	-	-	-	-	[k]
		-	5	-	-	-	-	-	-	-	[l]
		-	-	1 f/cc	-	-	-	-	-	-	[m]
	QC 12/2012	-	-	1 f/cc	-	-	-	-	-	-	[n]
		-	10	-	-	-	-	-	-	-	[o]
Talc , not containing asbestiform fibres	AB 4/2009	-	2	-	-	-	-	-	-	-	[e]
	BC 4/2012	-	2	-	-	-	-	-	-	-	[b]
		-	-	0.1 f/cc	-	-	-	-	-	-	
	ON 1/2013	-	2	-	-	-	-	-	-	-	[c]
		-	2	-	-	-	-	-	-	-	[p]
		-	-	2 f/cc	-	-	-	-	-	-	
	QC 12/2012	-	3	-	-	-	-	-	-	-	[d]
3,6-diazaoctanethylenediamin	ON 1/2013	0.5	3	-	-	-	-	-	-	-	[1]
	US AIHA 10/2011	1	-	-	-	-	-	-	-	-	[1]

Form: [a]Respirable particulate [b]Respirable [c]Respirable fraction: means that size fraction of the airborne particulate deposited in the gas-exchange region of the respiratory tract and collected during air sampling with a particle size- selective device that, (a) meets the ACGIH particle size–selective sampling criteria for airborne particulate matter; and (b) has the cut point of 4 µm at 50 per cent collection efficiency. [d]The value is for particulate matter containing no asbestos and < 1 per cent crystalline silica. [e]Respirable dust. [f]Inhalable fraction [g]Respirable fibers: length greater than 5 uM; aspect ratio equal to or greater than 3:1 as determined by the membrane filter method at 400-450X magnification (4-mm objective) phase contrast illumination. [h]Fibres [i]Fibres, total particulate [j]Inhalable [k]Fiber [l]Inhalable fraction: means that size fraction of the airborne particulate deposited anywhere in the respiratory tract and collected during air sampling with a particle size-selective device that, (a) meets the ACGIH particle size-selective sampling criteria for airborne particulate matter; and (b) has the cut point of 100 µm at 50 per cent collection efficiency. [m]Respirable fibres: length > 5µm; aspect ratio ≥3:1, as determined by the membrane filter method at 400-450 times magnification (4-mm objective), using phase-contrast illumination. [n]RESPIRABLE FIBRES (other than respirable asbestos fibres) : Objects, other than respirable asbestos fibres, longer than 5 µm, having a diameter of less than 3 µm and a ratio of length to diameter of more than 3 :1. [o]Total dust. [p]Respirable fraction [q]Total dust

Appropriate engineering controls No special ventilation requirements. Good general ventilation should be sufficient to control worker exposure to airborne contaminants. If this product contains ingredients with exposure limits, use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure below any recommended or statutory limits.

Environmental exposure controls Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures	Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Contaminated work clothing should not be allowed out of the workplace. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.
Respiratory protection	Use a properly fitted, particulate filter respirator complying with an approved standard if a risk assessment indicates this is necessary. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Skin Protection

Hand protection	Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.
Body protection	Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Other skin protection	Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Eye/face protection	Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with sideshields.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical and Chemical Properties

Physical State	Solid		
Appearance	Metallic. Gray-Beige	**Odor**	Ethereal
Color	Metallic. Gray-Beige	**Odor Threshold**	No information available

Property	**Values**	**Remarks/ Method**
pH	No data available	None known
Melting / freezing point	No data available	None known
Boiling point / boiling range	No data available	None known
Flash Point	Closed cup: >93° C	None known
Evaporation Rate	No data available	None known
Flammability (solid, gas)	Flammable in the presence of the following materials or conditions: open flames, sparks and static discharge.	None known
Flammability Limit in Air		
Upper flammability limit	No data available	
Lower flammability limit	No data available	
Vapor pressure	No data available	None known
Vapor density	No data available	None known

Specific Gravity	1.741	None known
Water Solubility	Insoluble in water	None known
Solubility in other solvents	No data available	None known
Partition coefficient: n-octanol/water	No data available	None known
Autoignition temperature	No data available	None known
Decomposition temperature	>200° C	None known
Kinematic viscosity	No data available	None known
Dynamic viscosity	No data available	None known
Explosive properties	No data available	
Oxidizing Properties	No data available	

Other Information

Softening Point	No data available
VOC Content (%)	0
Particle Size	No data available
Particle Size Distribution	

10. STABILITY AND REACTIVITY

Reactivity
No data available.

Chemical stability
Stable under recommended storage conditions.

Possibility of Hazardous Reactions
None under normal processing.

Hazardous Polymerization
Hazardous polymerization does not occur.

Conditions to avoid
Excessive heat.

Incompatible materials
Strong acids. Strong oxidizing agents. Strong bases.

Hazardous Decomposition Products
Carbon oxides.

11. TOXICOLOGICAL INFORMATION

Information on toxicological effects

Acute toxicity	No specific data.
Irritation/Corrosion	No specific data
Sensitization	No specific data.
Mutagenicity	No specific data.
Carcinogenicity	No specific data.

Classification

Product/ingredient name	OSHA	IARC	NTP
cristobalite	-	1	Known to be a human carcinogen.
Crystalline silica non-respirable	-	1	Known to be a human carcinogen.

Reproductive toxicity No specific data
Teratogenicity No specific data.
Specific target organ toxicity (single exposure) No specific data.
Specific target organ toxicity (repeated exposure) No specific data.
Aspiration hazard No specific data.
Information on the likely routes of exposure Not available

Potential acute health effects

Eye contact No known significant effects or critical hazards.
Inhalation Exposure to decomposition products may cause a health hazard. Serious effects may be delayed following exposure.
Skin contact May cause an allergic skin reaction.
Ingestion No known significant effects or critical hazards.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact No specific data

Inhalation No specific data.

Skin contact Adverse symptoms may include the following:
irritation
redness

Ingestion No specific data

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure
Potential immediate effects Not available
Potential delayed effects Not available

Long term exposure
Potential immediate effects Not available
Potential delayed effects Not available

Potential chronic health effects No specific data.

General Once sensitized, a severe allergic reaction may occur when subsequently exposed to very low levels.
Carcinogenicity No known significant effects or critical hazards.
Mutagenicity No known significant effects or critical hazards.
Teratogenicity No known significant effects or critical hazards.
Developmental effects No known significant effects or critical hazards.
Fertility effects No known significant effects or critical hazards.

Numerical measures of toxicity
Acute toxicity estimates No specific data.

12. ECOLOGICAL INFORMATION

Toxicity	No specific data.
Persistence and degradability	No specific data.
Bioaccumulative potential	No specific data.
Mobility in soil	
Soil/water partition coefficient (K_{oc})	Not available
Other adverse effects	No known significant effects or critical hazards.

13. DISPOSAL CONSIDERATIONS

Waste treatment methods

Disposal methods	This material, as supplied, is not a hazardous waste according to Federal regulations (40 CFR 261). This material could become a hazardous waste if it is mixed with or otherwise comes in contact with a hazardous waste, if chemical additions are made to this material, or if the material is processed or otherwise altered. Consult 40 CFR 261 to determine whether the altered material is a hazardous waste. Consult the appropriate state, regional, or local regulations for additional requirements.
Contaminated Packaging	Dispose of contents/containers in accordance with local regulations.

14. TRANSPORT INFORMATION

DOT	NOT REGULATED
Proper Shipping Name	NON REGULATED
Hazard Class	N/A
Marine Pollutant	This product contains a chemical which is listed as a marine pollutant according to DOT
TDG	Not regulated
MEX	Not regulated
ICAO	Not regulated
IATA	Not regulated
Proper Shipping Name	NON REGULATED
Hazard Class	N/A
IMDG/IMO	Not regulated
Hazard Class	N/A
Marine Pollutant	Product is a marine pollutant according to the criteria set by IMDG/IMO
RID	Not regulated
ADR	Not regulated
ADN	Not regulated

15. REGULATORY INFORMATION

United States

U.S. Federal regulations — **TSCA 8(a) PAIR:** Siloxanes and Silicones, di-Me, reaction products with silica
TSCA 8(a) CDR Exempt/Partial exemption: Not determined
United States inventory (TSCA 8b): All components are listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) — Not listed

Clean Air Act Section 602 Class I Substances — Not listed

Clean Air Act Section 602 Class II Substances — Not listed

SARA 302/304

Composition/information on ingredients — No products were found

SARA 304 RQ — Not applicable

SARA 311/312

Classification — Immediate (acute) health hazard

Composition/information on ingredients

Name	%	Fire hazard	Sudden release of pressure	Reactive	Immediate (acute) health hazard	Delayed (chronic) health hazard
Cristobalite	10-30	No.	No.	No.	No.	Yes
crystalline silica non-respirable	10-30	No.	No.	No.	No.	Yes

State regulations

Massachusetts — The following components are listed: SOAPSTONE; MINERAL WOOL FIBER

New York — None of the components are listed.

New Jersey — The following components are listed: SOAPSTONE, SILICA, QUARTZ; QUARTZ (SiO_2); FERROSILICON; FERROCERIUM

Pennsylvania — The following components are listed: SOAPSTONE DUST, QUARTZ (SiO_2)

Minnesota Hazardous Substances — None of the components are listed.

California Prop. 65 — **WARNING:** This product contains a chemical known to the State of California to cause cancer

Ingredient Name	Cancer	Reproductive	No significant risk level	Maximum acceptable dosage level
Talc, not containing asbestiform fibres	Yes.	No.	No.	No.
cristobalite	Yes.	No.	No.	No.
Crystalline silica non-respirable	Yes.	No.	No	No

Canada

WHMIS (Canada) Class D-2A: Material causing other toxic effects (Very toxic).

Canadian lists

Canadian NPRI	None of the components are listed.
CEPA Toxic substances	None of the components are listed.
Canada inventory	All components are listed or exempted.

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all the information required by the Controlled Products Regulations.

International regulations

International lists

Australia inventory (AICS): All components are listed or exempted.
China inventory (IECSC): Not determined.
Japan inventory: Not determined.
Korea inventory: All components are listed or exempted.
Malaysia Inventory (EHS Register): Not determined.
New Zealand Inventory of Chemicals (NZIoC): All components are listed or exempted.
Philippines inventory (PICCS): All components are listed or exempted.
Taiwan inventory (CSNN): Not determined.

Substances of very high concern None of the components are listed.

16. OTHER INFORMATION

Key to abbreviations

ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL 73/78 = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

Notice to reader

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End of Safety Data Sheet