Converting Sugarcane Waste into Charcoal for Haiti

by

Etienne Clement Toussaint

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

Signature of Author:____
Department of Mechanical Engineering
May 11, 2007

Certified by:____
Alexander Slocum
Professor of Mechanical Engineering
Thesis Supervisor

Accepted by:____
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

Converting Sugarcane Waste into Charcoal for Haiti

by

Etienne Clement Toussaint

Submitted to the Department of Mechanical Engineering
on May 11, 2007 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in Engineering
as recommended by the Department of Mechanical Engineering

ABSTRACT

In Haiti, most families have traditionally relied on wood and wood-derived charcoal as their primary fuel source for indoor cooking. This resource has proven to be unsustainable, however, as over 90% of the Haitian countryside has already been deforested and wood is now in low supply. As a poor country, importing fuel is not a viable option and thus, the ability to utilize renewable energy sources is critical. The work of the Edgerton Development Lab, under the guidance of Amy Smith, has developed a process utilizing an oil drum kiln to convert readily available agricultural waste from sugarcane, known as bagasse, into clean burning charcoal briquettes.

In order to improve the efficiency of the existing oil drum kiln, this research will explore the design of a brick kiln that is relevant for the social dynamic of developing countries, inexpensive to manufacture and simple to operate. By defining the best system applicable to the Haitian context, this research will enable the efficient production of charcoal. This research will also define the shape of the chamber and the steps involved in the conversion process, enabling Haitians to make use of their natural resources to address a critical energy need. In addition, the enhanced energy efficiency will reduce the production time of the charcoal briquettes. Lastly, this research will explore how this technology can be best integrated into the existing culture and lifestyle of the Haitian community and propose a strategy for community participation.

Thesis Supervisor: Alexander Slocum
Title: Professor of Mechanical Engineering

Table of Contents

1. Introduction

1.1 Motivation for Research

The development of efficient kilns to convert agricultural waste into clean burning charcoal briquettes can simultaneously reduce dependency on foreign oil, deforestation pressure, and the harmful effects of high smoke levels in many developing countries. The growing prices of oil, coupled with the limited resources of poor nations, highlight just some the complex challenges faces by communities where individuals struggle to simply secure adequate cooking fuel to sustain their families. In Haiti, in particular, most families have traditionally relied on wood and wood-derived charcoal as their primary cooking fuel. This fuel source is unsustainable, however, as over 90% of the country is currently deforested. [1] Not only will the energy source soon be depleted, but the current forestation holds a strong connection to the existing wetlands and natural water systems, which directly impact both water acquisition and water quality in many communities. In addition, the usage of wood and dung indoors leads to smoke levels that have been detrimental to the health of many Haitians, causing afflictions like Acute Lower Respiratory Infection (ALRI) and Chronic Obstructive Pulmonary Disease. [1] Importing fuel is not a realistic option because of price and thus, tapping into renewable energy sources proves to be a necessary alternative. The usage of clean burning charcoal derived from agricultural waste can address these issues.

While wood is scarce, Haiti does have an abundance of agricultural waste that can be used as fuel. One specific agricultural waste found in Haiti, termed *bagasse*, is the fibrous remains of sugarcane processing. [3] While the actual bagasse cannot be used directly as fuel in households because of the thick fumes, the waste can be converted into clean-burning charcoal briquettes utilizing a thermally insulated combustion chamber, or a kiln. In addition, once mass produced, charcoal briquettes can be stored for extended periods of time without decomposing. [3] Farmers employing this resource will not only be able to provide a clean fuel source for their families, but can potentially sell briquettes to others in their community, spurring future economic development.

One current method used to convert the agricultural waste into charcoal briquettes incorporates a specified series of steps into the simple design of an oil drum kiln. This design for Haiti, spawned from the Edgerton Development Lab under the guidance of Amy Smith, provides a sustainable, simple, and low cost way for Haitians to tap into their current resources. This thesis serves to advance that body of knowledge and increase the ability of developing countries to truly harness the power of agricultural waste. By exploring the critical components of a low-cost brick kiln design, this research intends to identify an alternative approach for the conversion of waste into charcoal that will increase energy efficiency, reduce the production time of briquettes, and maintain low costs and simplicity. After identifying a suitable brick kiln design, this research will explore how the system can be sustainable integrated into the culture of Haiti.

1.2 Application in Haiti

The Republic of Haiti occupies one-third of the Caribbean island of Hispaniola with the Dominican Republic. The former French colony was the first independent black republic, establishing its independence on January 1, 1804, as well as the only nation to successfully stage a slave revolt. Before that time, enslavement and the brutal treatment of natives led to massive deaths amongst the native population and motivated the importation of African slaves to the island. Today, about 90% of Haitians are of African descent. [1] In addition, Haiti is the least-developed country in the Western Hemisphere and is continuing to fall behind other low-income developing countries, both in terms of social and economic stability. Haiti ranks 153rd out of 177 countries in the UN Human Development Index and about 80% of the population currently live in poverty. [4]

Approximately 70% of the Haitian community depends on the agricultural sector through small-scale subsistence farming. [1] The main crops include coffee, mangoes, sugarcane, rice, corn, sorghum, and wood. [4] The role of agriculture in the economy, however, has been recently impacted by poor technology and inadequate resources amongst farmers, who often choose to seek opportunities in the city.

In addition, experts claim that "highly inefficient exploitation of the scarce natural resources of the countryside caused severe deforestation and soil erosion and constituted the primary cause of the decline in agricultural productivity." [5] Deforestation has also led to massive flooding because the destruction of hillside forests eliminates the natural protection against heavy rains. A large percentage of the land area in Haiti is susceptible to land erosion, as demonstrated by Figure 1.

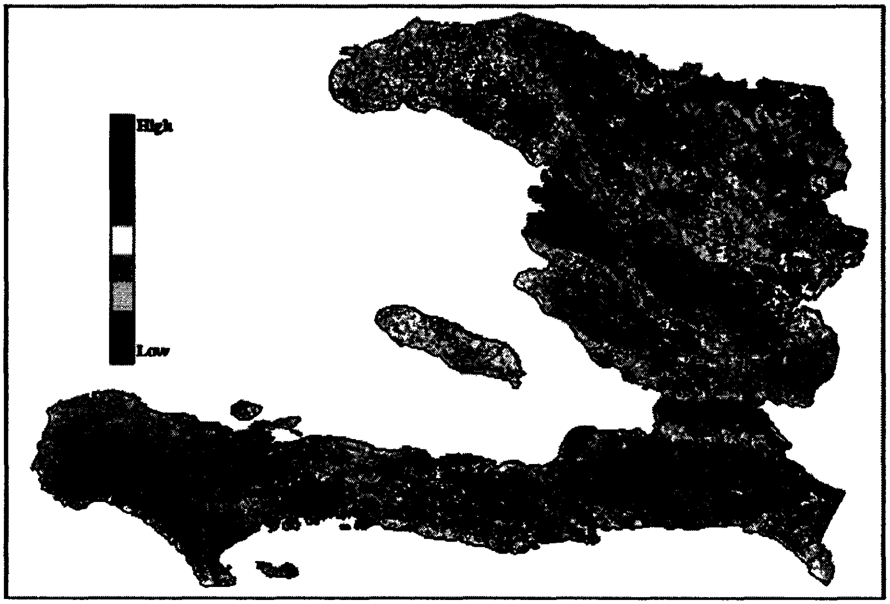


Figure 1. Land Susceptible to Soil Erosion in Haiti

The majority of Haitians depend on solid cooking fuels, which include firewood, straw, dung, charcoal, and coal. Table 1 below highlights the percentage of solid cooking fuels used versus modern cooking fuels, which include electricity, LPG, natural gas, kerosene, and gasoline.

Urban %			Rural %			National %		
Modern	Solid	Total	Modern	Solid	Total	Modern	Solid	Total
7.9	91.9	100	0.7	99.2	100	4.1	95.8	100

Table 1: Percentage of Solid Cooking Fuels vs. Modern Cooking Fuels [6]

In addition, the majority of women, across urban ands rural areas use charcoal and firewood as their primary source of cooking fuel, as highlighted in Table 2. Firewood is primarily used in rural areas, which serves to further deforestation.

	Urban %	Rural %	Total %
Electricty	0.0	0.0	0.0
LPG, Natural Gas	2.9	0.3	1.5
Biogas	1.7	0.2	0.9
Kerosene	3.3	0.2	1.7
Coal, Lignite	0.0	0.0	0.0
Charcoal	**86.6**	**17.9**	**49.4**
Firewood, Straw	**5.3**	**81.3**	**46.4**
Dung	0.0	0.0	0.0
Gasoline	0.0	0.0	0.0
Other	0.1	0.1	0.1
Total Percentage	100.0	100.0	100.0
Number of Women	4655	5499	10154

Table 2: Fuel Sources Used in Urban and Rural Communities [6]

These problems have resulted in very high unemployment rate and Haitians would certainly benefit from opportunities that promote economic development, such as using agricultural waste to produce charcoal.

2. Technology Overview

2.1 Necessary Resources

The conversion of agricultural waste into clean burning charcoal briquettes is a detailed, yet simple process that requires three critical components: agricultural waste, a thermally insulated chamber, and a binding agent to form the charcoal briquettes from the char.

2.1.1 Agricultural Waste – Bagasse

Sugar cane, a large bamboo-like stalk that grows 8 to 15 feet tall, contains sucrose that is processed into sugar by crushing the stalk to extract their juice. [7] The cane is typically harvested through hand cutting, machine cutting, or mechanical raking, all of which yield stalks with a variety of trash and dirt content. Cane harvested using the hand method will contain much more trash, dirt, and mud than those harvested using machines. When the canes are delivered to a mill, they are usually washed, chopped into smaller pieces, and then crushed, leaving behind a large amount of matted cellulose fiber residue. This biomass, a term used for biodegradable wastes that can be used for fuel, is known as bagasse. Bagasse varies in its composition, consistency and heating value depending on the particular climate, soil composition, harvesting method, and efficiency of the milling process. Typically, bagasse has a heating value of between 3000 to 4000 Btu/lb (1600 to 2200 kcal/kg) on a wet, as-fired basis. This is the amount of heat generated per pound of bagasse less the heat required to evaporate its moisture. Dryer bagasse has a higher calorific value. In addition, bagasse typically contains between 45 to 55 percent moisture by weight. The sulfur and nitrogen contents of bagasse are also very low, usually near or below 0.1 weight percent. [7]

Often, bagasse is disposed by burning in open fields or by using it to partially fuel the sugar extraction process in large sugar refineries. However, the thick smoke produced during burning makes it a poor fuel source for indoor cooking. Thus, it must be converted into charcoal, a clean burning fuel.

2.1.2 Thermally Insulated Chamber

Charcoal is produced when organic matter is heated to very high temperatures in a low-oxygen environment, yielding the necessary carbon nature of the briquettes. [8] The thermally insulated chamber, commonly known as a kiln, is necessary to heat the agricultural waste. The kiln creates the necessary low-oxygen, high temperature environment, driving water and other particulates out of the agricultural waste and leaving charcoal behind. Charcoal Kilns typically require regulated air flow in the chamber to be adjusted at specified times because the biomass usually serves as both the fuel to heat the kiln and the material being carbonized. In our case, we want the majority of the bagasse to be left unburned to allow for its conversion into charcoal.

Figure 2. Traditional Charcoal Kilns in Brazil

2.1.3 Properties of Charcoal

Coal is a sedimentary rock produced from plant remains by partial decomposition in the absence of atmospheric oxygen. The net result of this decomposition is a material having a lower amount of oxygen and hydrogen and higher carbon content than the original matter. The steps in the breakdown of the plant remains lead to the successive formation of peat, then lignite, sub-bituminous coal, bituminous coal and anthracite. [9]

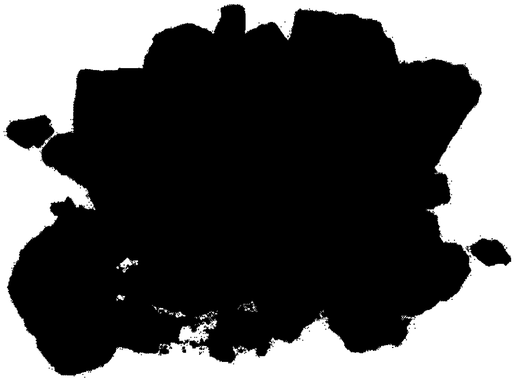


Figure 3. Conventional Charcoal

Charcoal is the residue obtained when carbonaceous materials, of either animal or vegetable origin, are partially burned or heated so that tarry and volatile matter is removed; in most case the residues may be roughly described as impure carbon.[10] There are five products and by products emitted during charcoal production: charcoal, noncondensible gases (carbon monoxide, carbon dioxide, methane, and ethane), pyroacids (primarily acetic acid and methanol), tars and heavy oils, and a large amount of water. [7] Most carbonizing systems have a much higher efficiency when fed with dry materials because the removal of water requires large inputs of heat energy.

Charcoal is a relatively "clean" substance when compared to some other fossil fuels, making it a good choice to use as a cooking fuel. It contains very little sulfur and mercury and is also very low in nitrogen and ash. The material is also highly reactive due to its chemical composition. During the formation of charcoal, the molecular framework of the sugars composing biomass is rearranged to form aromatic structures. Not all bonds are broken, resulting in a carbonaceous solid that is porous at the molecular level and consequently, highly reactive. [11]

Charcoal Production

There are two ways to make charcoal in a kiln. The direct method involves burning the biomass material, such as wood, and controlling the air intake to char the material and not burn it into ash. The indirect method involves using an outside heat source to essentially cook the material while it is inside of a retort. The retort is a container that holds the biomass material while allowing the volatile gases to escape. The indirect method typically yields more charcoal for a given volume of material because no material is directly lost during the burning process.

The effectiveness of a system for charcoal production is often determined by analyzing the charcoal yield. The charcoal yield of a kiln is given by $y_{char} = m_{char} / m_{bio}$. [11] In this equation, m_{bio} is the dry mass of the feedstock loaded into the kiln and m_{char} is the dry mass of the charcoal taken from the kiln. One must note, however, that this value does not take into account the fixed carbon content of the particular feedstock, which can vary widely.

Most conventional kilns and retorts for making charcoal operate at a low efficiency levels. This is because pyrolysis abruptly transforms wood into a tarry vapor of organic compounds with noncondensable gases. The tarry vapors quickly escape the heated region of the system without forming charcoal, constituting a significant loss of carbon.

The performance of a kiln is often measured by its ability to control gas-phase conditions in the interior. In a conventional kiln, the moisture content of the feedstock greatly impacts the cycle time and charcoal yield. In systems that utilize the feed as a heat source, biomass with a higher moisture content requires more feed to be burned to dry the remainder of the material before carbonization. However, literature on biomass pyrolysis chemistry highlights the influence of pressure on pyrolysis. In a retort system, with an externally heated vessel, an increase in the moisture can in fact enhance the charcoal production yield at high temperatures. [11]

This is because these systems operate at elevated pressures and research has demonstrated that steam pyrolysis at high temperatures preferentially removes highly reactive carbon that blocks the intrinsic pore structure of biocarbons. [11] Under pressure, the tarry pyrolytic vapors have a smaller specific volume, increasing their residence time in the material. The tarry vapor is composed of a mixture of reactive organic compounds – including vapor-phase sugars and anhydrosugars, which are unstable at high temperatures. They rapidly decompose on the surface of the charcoal and produce secondary charcoal, increasing carbon content. When coupled with low gas flows, there is an even higher percentage of char produced. [11] The prolonged vapor-phase residence time and increased concentrations of vapors has a positive effect on the carbonization process.

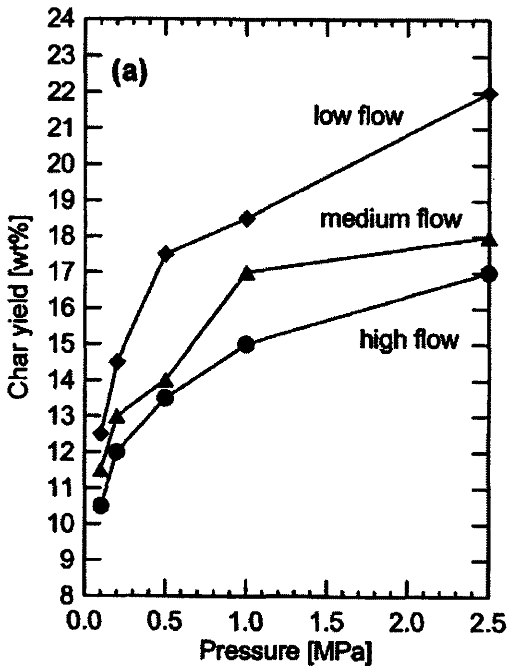


Figure 4. Effects of Pressure and Gas Flow on the Yield of Char from Cellulose [11]

During the charcoal production process, the heating rate can also have an impact on the carbon content of the product. Research has demonstrated that short carbonization times with sudden exposure of biomass feed to high temperatures can give low carbon yields. [11] The definition of "slow" or "rapid" carbonization, however, has not been quantified for all biomass materials.

2.2 Conversion Process

2.2.1 Combustion Theory and Carbonization

Biomass is a term used to describe all organic matter existing on the earth produced by photosynthesis. The usage of energy from biomass, most commonly obtained through fire throughout history, has played a critical role in the development of modern technologies and cities. The energy from solid biomass (trees, crops, residues, etc) is harnessed through the process of combustion, which allows the material to be carbonized. Carbonization takes place when organic matter is raised to high temperatures in the absence of oxygen.

Three main stages exist in the biomass combustion process:

1. The moisture embedded in the solid biomass must be removed before carbonization can take place. This can be achieved with drying prior to burning. If water remains, then the energy required to remove it is obtained by the burning of some of the biomass material inside of the kiln itself. This decreases the amount of material that can be converted into useful charcoal. Water is evaporated between 100° and 170° C. [12]

2. The biomass then undergoes pyrolysis, which is the chemical decomposition of organic material in the absence of oxygen. Between 170° and 270° C, carbon monoxide and carbon dioxide, as well as condensable vapours in the material are released through the process of thermal desorption.[12]

3. Pyrolysis leads to carbonization of the material. Between 270° and 280° C an exothermic reaction begins that raises the temperature inside the chamber, generating heat. The development of carbon monoxide and carbon dioxide eventually ceases, but condensable vapours continue to be emitted and the temperature continues to rise to between 400° and 450° C. [12] The remaining oxygen is used to break down the chemical properties of the material until only the carbonized residue remains – charcoal.

Thus we anticipate a final internal temperature of approximately 500° C. Lower temperatures do in fact give a higher yield of charcoal. However, that charcoal is low grade, having a high percentage of tarry residue and consequently, not burning with a clean smoke-free flame. Good commercial charcoal with a fixed carbon content of about 75% calls for a final carbonizing temperature of about 500° C. [12]

3. Design Process

3.1 Defining a Strategy

The deterministic design process allows one to approach any design challenge in a systematic and organized fashion. This system was utilized throughout the design phase of this project to assist in creating an efficient system and process that could be easily understood by a non-scientific audience. The six categories of thought involved in the process include (1) defining Functional Requirements, (2) establishing Design Parameters, (3) detailing necessary Analysis, (4) highlighting References, (5) outlining Risks, and (6) listing available Countermeasures. Functional requirements are the actions that the design must accomplish. Design Parameters are ideas on how to achieve the functional requirements. The Analysis describes the physics that governs each Design Parameter to allow for sensitivity studies. Outlining Risks includes projecting what might go wrong with the pursuit of each Design Parameter. Finally, Countermeasures are alternative paths to be taken if the risks prove to be too great.

The focus of this research is to convert agricultural waste – bagasse in this case – into a usable source of biofuel, namely charcoal. The chosen strategy is to utilize a brick kiln to facilitate this conversion process, which creates a high temperature environment to burn and carbonize the agricultural waste. The following table details the six categories of the deterministic design process for the chosen strategy of a brick kiln.

Functional Requirements	Design Parameters	Analysis	Reference	Risks	Countermeasures
"Pre-treat" the bagasse before the burning process to reduce heating time and energy loss	1) Dry the bagasse inside of a retort that is located inside of the kiln during the burning process	1) Thermal analysis of heat through retort	1) 2) & 3) Course 2.005 Textbook; www.engineeringtoolbox.com; MIT professors	1) Destroying the bagasse because the retort becomes too hot	1) & 2) Use more insulative material or magnify thickness of wall to reduce heat flow
	2) Use the waste heat from the kiln to dry the bagasse in an external chamber	1) Thermal analysis of heat out of chimney		2) The heat may be lost in the transfer process	
	3) Create a pressurized chamber, eliminating the need to dry the bagasse	3) Amount of pressure needed in system		3) Inability to obtain necessary steam pressure to bypass drying benefits	3) Use an external force to increase pressure during operation
Heat the combustion chamber to necessary temperature for carbonization	1) Burn some of the bagasse on the floor of the kiln	1) & 2) Thermal analysis of heat produced from burning bagasse or other substitute material	1) & 2) Course 2.005 Textbook; www.engineeringtoolbox.com; MIT professors	1) & 2) No production of charcoal due to insufficient heating of chamber	1) & 2) Increase intensity of source of heat by expanding size of kiln relative to size of materials
	2) Use an exterior heating source - solar energy or wood				
Create low-oxygen environment after desired temperature is achieved to carbonize material	1) Manually decrease and eventually eliminate airflow through air inlets and chimney using dampers	1) & 2) Analysis of air flow given specified dimensions and impact on heat	1) & 2) Course 2.005 Textbook; www.engineeringtoolbox.com; MIT professors	1) & 2) Inefficient production of charcoal due to too much air leaking into system	1) Decrease size of air inlets
	2) Heat material inside of a retort with few air holes, creating a low oxygen environment				2) Use a double-skin retort

Table 3: Deterministic Design Chart for Chose Strategy of Brick Kiln

3.1.1 Design Constraints and Design Criteria

There are three main design constraints for this project:

1. *The brick kiln must be simple and easy to operate.*
2. *The system must be safe and environmentally friendly, minimizing any exposure to harmful particulates.*
3. *The design must incorporate materials that are locally available or accessible to the Haitian community.*

These design constraints will shape the design criteria, which are listed below, that will be used to evaluate the various concepts that could potentially satisfy our initial strategy. By exploring the various elements of the design criteria in each concept and observing how they compare, I will determine which combination of characteristics from the concepts can yield the best design.

Design Criteria	Description
Integrated Steps	The drying process, heating process, and carbonization process should all be incorporated into the same design as well as preparing the charcoal fines for the next stage of the process, which is forming briquettes.
Simplicity	The process should be simple to learn and operate, allowing the system to be sustainable without the help of NGOs and outside agencies.
Safety	The technology must reduce operators' exposure to charcoal particulates, high temperatures, and other associated dangers.
Cost	A minimal amount of parts and a simplified manufacturing process will allow for low costs, making this technology appropriate for the Haitian economy.
Maintenance	The technology must be locally repairable.
Materials	The technology should incorporate locally available resources that are accessible and are durable, minimizing the need for replacements.
Charcoal Quality	The technology should produce charcoal fines with high energy content.

Table 4: Design Criteria for Brick Kiln Concept

3.2 Outlining and Analyzing Concepts

There a number of brick kilns currently being used in developing countries that fall in line with the established design criteria. Each concept will be explored to better understand their similarities and differences.

3.2.1 Charcoal Kiln Design in Developing Countries

The kiln must be simple to construct, able to withstand thermal stresses during heating and cooling and mechanical stresses during loading and unloading, and able to withstand diverse environmental conditions. The kiln must allow the user to manually control the flow of air through the internal chamber to control the carbonization process, which should be consistent through the entire area. If the flow of air is not controlled, some of the charcoal may burn inside of the chamber. In addition, the kiln should allow for airtight sealing of the chamber during the cooling process.

A survey of brick kiln technologies reveals the range of sizes, materials, associated cost, and regional and cultural appropriateness within which to situate a kiln designed for converting bagasse into charcoal. Most brick kilns are separated into two categories: hangar kilns, which are rectangular in shape, and round brick kilns. [13] A popular hangar kiln used in the United States is the Missouri kiln, while three popular round brick kilns are the Argentine half-orange kiln, the Brazilian beehive kiln, and the European Schwartz kiln.

The European Schwartz model uses an external fuel source to heat the organic material, in addition to a large amount of steel for its construction, making it unsuitable for the developing world where energy resources and money for steel are scarce. The Missouri, Argentine, and Brazilian kiln all burn part of the organic material inside of the combustion chamber to provide the necessary heat for carbonization, which work well for our sugarcane waste to charcoal process. However, the Missouri kiln is typically constructed with reinforced concrete and steel for mechanical loading and unloading, making it extremely costly and difficult to cool in high temperature environments, a poor choice for the developing world.

Figure 5. Missouri Kiln Made of Reinforced Concrete

The two most popular kiln designs that have been implemented in developing nations already are the Argentine and the Brazilian kilns. [13]

The main advantages of Argentine and Brazilian Kilns are their ability to be constructed in a variety of sizes, built with local clay/sand bricks and mud mortar and little to no steel, withstand the heat of the sun and effects of rain, allow for manual control of burning, and ability to be cooled easily using clay slurry that allows it to be sealed hermetically during cooling.

3.2.1.1 Concept 1 – Argentine Kiln

Figure 6. Argentine Half-Orange Kiln

The Argentine kiln is built completely of bricks in a hemispherical shape, typically without the support of iron or steel beams. Two doors are placed opposite one another to load and unload the organic material into the chamber. The top of the kiln has a hole, called an "eye", while the base is comprised of several smaller holes evenly spaced throughout the area. The holes on the base are air inlets and the eye is an outlet for smoke to escape the chamber.

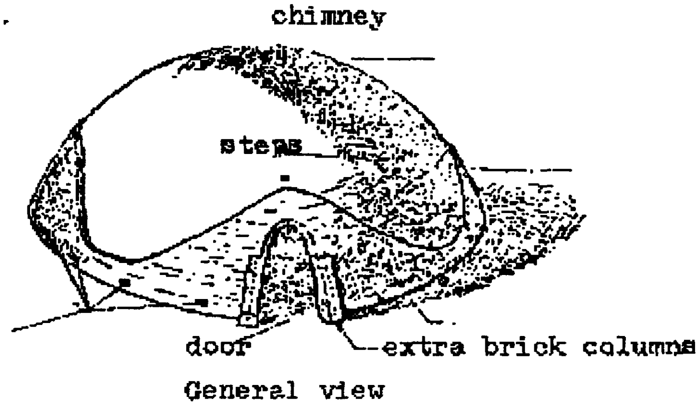


Figure 7. Argentine Half-Orange Kiln Schematic

After the Argentine kiln has been loaded with the organic material, while keeping both the holes at the base and the eye open, the fuel is lit through the upper hole.

Kiln Operation

During the first phase, white smoke is emitted through the chimney as the material loses its water content using the natural draft created with the air inlet portholes. Once the carbonization process has begun, the smoke becomes blue in color. The carbonization process is manually controlled by the opening and closing of the air hole at the base of the kiln. When the color becomes steady during the carbonization process the air inlet portholes are closed. When the smoke become transparent, the carbonization process is complete and the top hole is closed. During the cooling phase, all the holes are closed and the kiln is hermetically sealed with mud, which prevents any further entry of air.

3.2.1.2 Concept 2 – Brazilian Kiln

Figure 8. Brazilian Beehive Kiln

The beehive Brazilian kilns are comprised of a domed roof and a circular chamber, built entirely out of bricks. The shape of the beehive kiln allows for uniform carbonization of the material, as well as uniform cooling because the walls are completely in contact with the outside environment. In addition, small holes on the wall allow external control of the internal combustion.

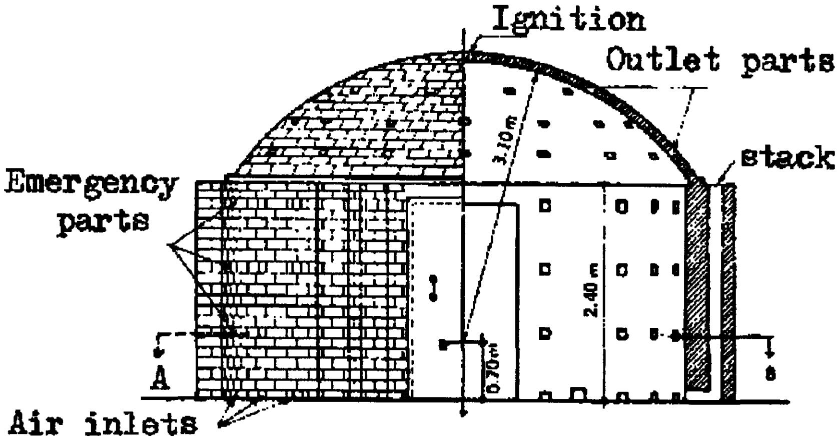


Figure 9. Brazilian Beehive Kiln Schematic

These kilns are easy to construct and can yield up to 62% in volume when operated properly. [13] The operation of the Brazilian kiln is identical to that of the Argentine kiln.

A variation of the beehive kiln is the slope type beehive kiln, which is built into a slope or hill that form its rear and side walls. The slope type kilns are easier to operate because they only have one air port to control while still producing a similar yield to the regular beehive kiln. However, the slope type kilns require a natural or artificial slope, as well as soil that will not crack under high temperatures allowing air to enter or collapse easily under the changing thermal conditions and loading.

3.2.1.3 Concept 3 – Charring Kiln

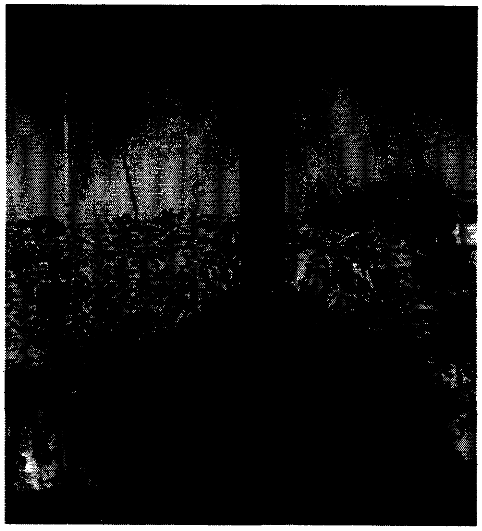


Figure 10. Charring Kiln from ARTI

The charring kiln is an oven-and-retort type kiln developed in India by the Appropriate Rural Technology Institute (ARTI) that claims to be more environmentally friend than other charcoaling technologies. The agricultural waste is stored inside of a metal retort, which is placed inside of an oven on a metal grate near the bottom. The oven is a cylindrical brick and mud structure. The retort is placed on the grate upside down so that the top lid, which has a small hole cut out in the center, is directly facing the fire. The fire in the bottom of the oven is produced using some of the sugarcane trash that is available. The volatile gases that enter the firebox from the hole in the metal retort contribute to the charring process by generating more heat in the chamber. When the volatile gasses have all been released, which is purported to take 15 to 20 minutes, the retort is taken out of the oven and replaced with another batch. This kiln can convert trash to char with 30% conversion efficiency. [14]

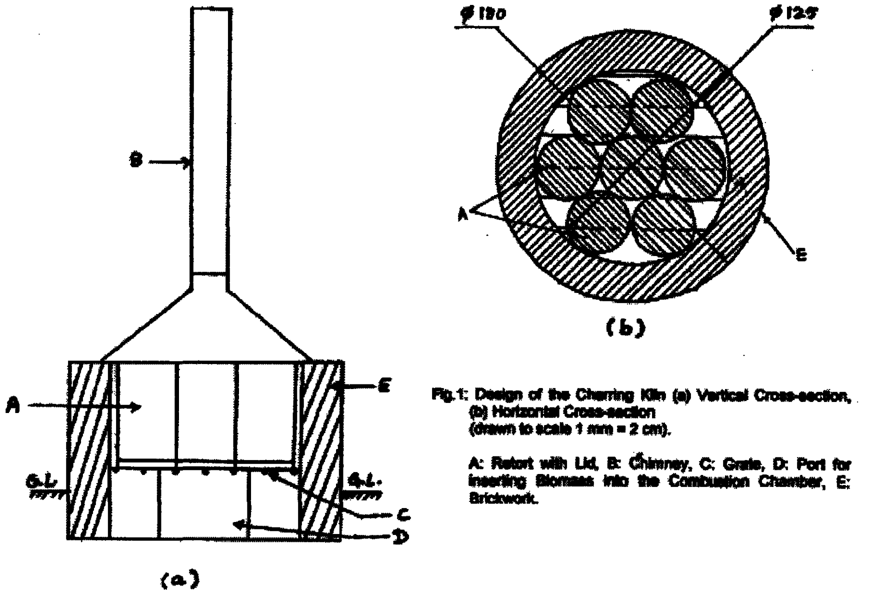


Fig.1: Design of the Charring Kiln (a) Vertical Cross-section, (b) Horizontal Cross-section (drawn to scale 1 mm = 2 cm).

A: Retort with Lid, B: Chimney, C: Grate, D: Port for inserting Biomass into the Combustion Chamber, E: Brickwork.

Figure 11. Charring Kiln Schematic

There a number of advantages to the oven-and-retort kiln. The kiln can be used to fire a number of different waste materials. In addition, the size of the oven and the size and number of retorts is variable and can be modified to accommodate different needs. The kiln can be a permanent structure with the biomass being transported from other locations, or a portable structure that can be taken to the source of the biomass.

3.2.2 Evaluating and Selecting Concept

Each of the selected brick kiln concepts has positive attributes that would be good additions to a kiln design for Haiti. To determine which characteristics should be incorporated and narrow the list of choices, each concept was evaluated relative to the design criteria previously established – integrated steps, simplicity, safety, cost, maintenance, materials, and charcoal quality. Two particular criteria were weighted twice as heavily as the others – simplicity and maintenance – because of their importance in enabling development projects to be successful in countries such as Haiti.

Design Criteria	Missouri Kiln	Argentine Kiln	Brazilian Kiln	Charring Kiln
Integrated Steps	**0**	**0**	**0**	**1**
Simplicity (*2)	**0**	**2**	**1.5**	**1**
Safety	**0**	**0**	**0**	**-1** (The chimney must be removed to refill retorts between cycles.)
Cost	**0**	**1**	**1**	**2** (Requires brick and metal retorts and chimney)
Maintenance (*2)	**0**	**0**	**0**	**1** (Easier to disassemble)
Materials	**0**	**1**	**1**	**0** (Metal retorts may not be available)
Charcoal Quality	**0**	**0**	**0**	**1** (Less material is wasted)
Total	**0**	**6**	**5**	**6**

Table 5. Pugh Chart ranking brick kiln concepts

The results of the Pugh chart indicated that the Argentine Kiln and the Charring Kiln were superior concepts. Upon closer inspection, however, they were certain characteristics of each concept that were critical to a good kiln concept. The charring kiln was not as safe as the Argentine and Brazilian Kilns because it required the chimney to be manually removed to replace the feedstock before each cycle. This was a feature I did not want to include into a final design. However, the simplicity of the charring kiln with a collection of pieces that could be easily disassembled was an attractive characteristic. I decided to combine elements of the two kiln designs an incorporate them into my final design. The elements that I chose were:

- A brick lining serving as the shell of the kiln using local materials
- A system of retorts inside of the kiln to carbonize the biomass material and the dry the material in preparation for a second cycle
- A chimney to facilitate natural draft through the system
- A slope in the base of the chimney to simulate a kiln with an arched roof
- A front loading door to ensure safety and promote simplicity
- A kiln with various pieces that can be "dissembled"

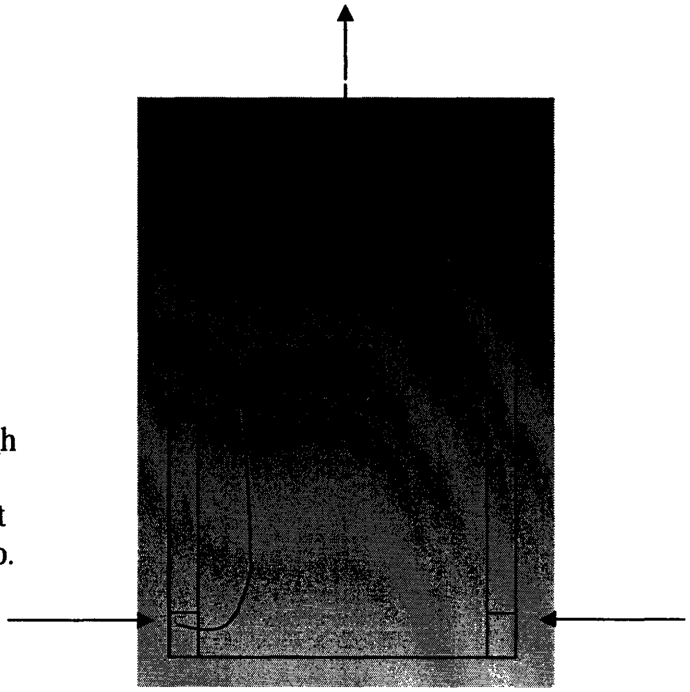
4. Proposed Final Design

4.1 Elements of Kiln Design

According to <u>The Kiln Book</u>, there are six critical factors that must be considered when designing a kiln. [9] These factors include the kind of kiln, the material that needs to be fired, the atmospheric conditions, available fuel, the location of the kiln, and the shelf size within the kiln.

Kiln Shape

A cube has been recognized as the best all purpose shape for a kiln because of the ability to have a more even distribution of heat inside the chamber. [9] The most efficient design for an updraft kiln, which is the typical design utilized for charcoal kilns, places the arch on the top of the cube. The flame and heat direction should follow the arch and should not be at right angles to the arch, which can cause irregular heating or hot spots. This requires strategic placement of ventilation holes along the exterior wall that will allow the flow of air to follow the arch design. A kiln with a domed roof can evade this complication.



Air flows into the kiln through vents in the bottom and out through the top.

Figure 12. Schematic of air flow through kiln

A specified dimension for combustion area is required for natural draft kilns, depending on the fuel used. For kilns that use wood as the fuel source, the ratio of the grate combustion area to the chimney cross sectional area at the base should be roughly 10 to 1. A value of 7 to 1 in wood kilns may allow for more forgiving firing techniques and more flexibility in chimney height. [9]

Chimney Design

A chimney is a device used to vent hot flue gases from a stove or furnace to the outside atmosphere. They are typically vertical to ensure smooth flow of the gases through the system. The design of the chimney is an important part of the kiln system. Chimneys operate on the principle that hot, less dense air inside of a chamber will rise above the cooler, denser air that exists on the outside. The rising gas creates a pressure difference called a 'natural draft', which draws combustion air into the chamber and expels the air through the chimney. [15] This partial vacuum continues to draw air into the chamber from the outside due to the pressure differential. Taller chimneys create a stronger draft, which impacts the speed of the flue gas flow through the system. An optimal height must be achieved to ensure that the air flows at the necessary speed to maintain the internal temperature of the chamber.

While a tall chimney increases velocity inside the firing chamber, too high of a chamber can pull heat out of the kiln, not allowing it to build up to a high temperature quickly. Conversely, too short of a chimney can decrease the draft rate, which does not pull enough oxygen into the kiln to allow proper combustion for temperature increase.

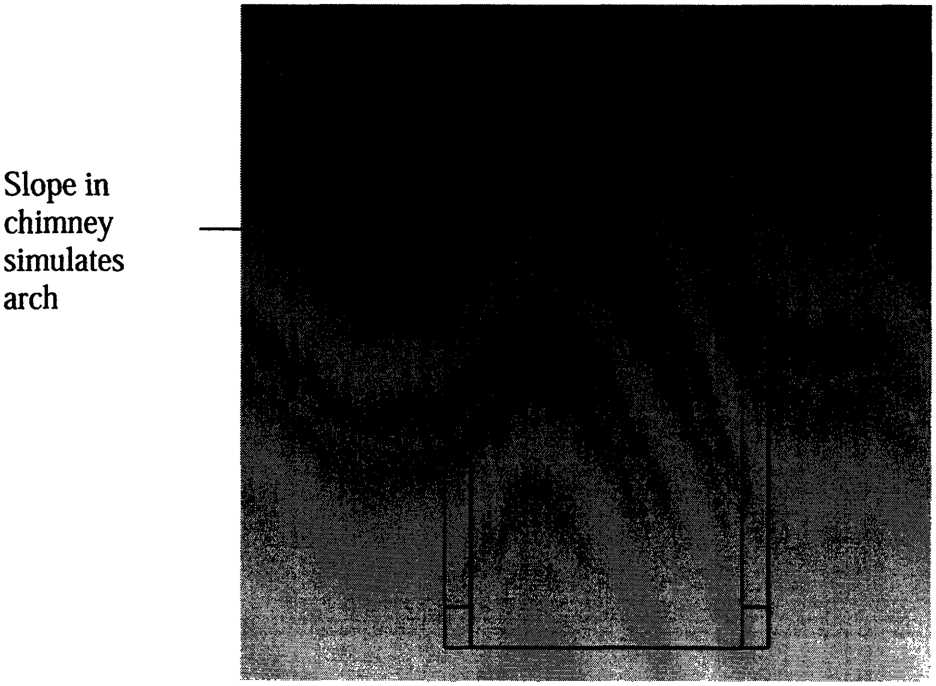


Figure 13. Schematic of chimney design on top of kiln

For natural draft kilns, there should be approximately 3 feet of chimney to every foot of downward pull, plus 1 foot of chimney to every 3 feet of horizontal pull. In addition, the chimney diameter should be approximately one-fourth to one-fifth the diameter of the chamber. Slope of the kiln also determines the chimney height. Building the kiln on a hill will reduce the chimney height requirements. Tapering the chimney can reduce atmospheric pressure and increases the speed of the draft, which should be 4 to 5 feet per second for natural draft kilns during the most efficient operation. [9]

Regulating Air Flow

In natural-draft kilns the inlet flue areas must be equal to the exit flue areas to allow for proper air flow throughout the system. Also, the area of the flue opening should be 10% of the floor area of the kiln, which strikes a balance between keeping hot gas in the kiln long enough to heat up the chamber and bring in new heated air. [16] Maintaining air flow is important in the combustion process to allow the kiln to achieve the desired temperature for carbonization of the material. The combined area of the inlets should be equivalent to the chimney cross sectional area. If the chimney cross section is made much larger than the inlet and exit flues in a natural draft kiln, tapering of the chimney must be done to ensure proper draft. Poor air circulation will impact the ability to produce a hot fire at the beginning of the cycle.

Other factors that influence kiln design include outside air temperature, as well as elevation. Elevation has a direct effect on the amount of oxygen present in the atmosphere because of the change in density of oxygen. At higher altitudes, the chimney diameter and flue sizes are increased to pull in more oxygen. In addition, kiln firing is more efficient at night when the air cools and becomes denser. At that time, more oxygen is present and the kiln can reach higher temperatures.

4.1.1 Brick Selection

The type of brick used to construct the kiln must be both resistant to thermal shock and a good insulator. The walls must insulate the material during carbonization to minimize heat loss and also conduct heat to enable the cooling phase to take place at a reasonable speed. [13] High strength bricks used in city buildings are not good choices because they are prone to crack under high temperatures. Typically, refractory materials are used to make bricks for kilns because of their ability to retain their strength at very high temperatures. Refractory materials must be strong at high temperatures and resistant to thermal shock, or rapid temperature change. The materials are also chemically inert, meaning they do not react with other elements or themselves, and have low thermal conductivities and coefficients of expansion, which defines their response to temperature change. [13]

A good refractory can be manufactured using inexpensive materials. This is important for developing countries, where resources are sparse. One simple refractory mix, which can be used to build a homemade furnace, is composed of 1.5 parts portland cement, 2 parts silica sand, 1.5 parts perlite, and 2 parts fireclay. [17]

Portland cement is plain cement powder and differs from masonry cement, which is a mixture of cement and sand. Masonry cement can be used alone with water in some cases because it may contain other components that provide beneficial characteristics like waterproofing. Perlite is a lightweight, heat-expanded volcanic material used in to loosen and aerate soil for plants. It is good for refractory mixes because it is not a good conductor of heat. Fireclay is typically sold in 50lbs packages from ceramic supply facilities and can be substituted with Bentonite clay. The first three components –

Portland cement, silica sand, and perlite – are mixed together thoroughly and the fireclay is added afterwards. [17] If these materials cannot be secured, a sandy clay mixture can be used with about 65% clay content and 20% sawdust to increase porosity. [13]

These materials could be donated to Haiti through an outside funding agency or NGO for construction.

4.2 Outlining and Analyzing Modules

4.2.1 Concept Design Overview

The concept for my final design incorporates elements of both the Argentine Kiln and the Charring Kiln. The brick kiln will be built in the shape of a cube with a permanent metal chimney on top that is sloped to simulate an arch, very similar to the Charring Kiln design. Inside of the brick kiln, there will be a series of metal bins that serve as holding containers for the bagasse during the drying and carbonization process. This particular design will incorporate two metal bins that will stack on top of one another inside of the kiln and will be placed on top of a metal grate above the fire box. Bagasse will be placed inside of each bin and a metal cover will be placed on top of the containers with an external weight on top of the cover. This weight can be in the form of a few bricks placed on top of the cover after the containers are full. A firebox under the grate will be loaded with extra bagasse to facilitate the heating process.[1] The diagram below demonstrates how the system with all containers will be placed inside of the kiln.

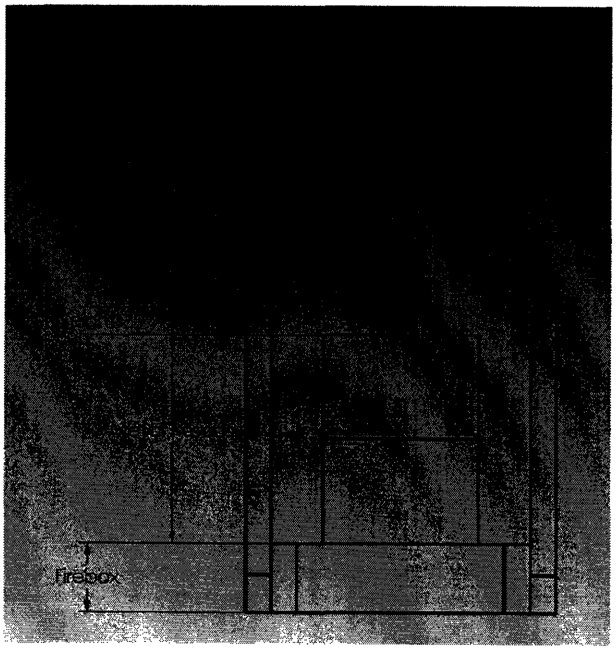


Figure 14. Schematic of complete system with retorts

---

[1] Refer to appendix (9.2) for further analysis

Kiln Dimensions

The size of the kiln was chosen relative to the amount of bagasse that needed to be converted into charcoal during a given cycle. This value was arbitrarily chosen to be consistent with the amount of charcoal produced using the oil drum kiln. Thus, the dimensions for the brick kiln facilitate a container system that yields the same amount of charcoal as the oil drum kiln. The brick kiln would realistically be made larger to use more bagasse and obtain a higher yield for each cycle. Also, the design only calls for two stacked containers; however, that number could be increased.

A cube shape was chosen to facilitate even distribution of heat through the system. Each wall is 3 feet in length and height. The chimney is a total of 4 feet in length. A ratio of 7 to 1 was used with the firebox floor and the chimney to determine chimney sizing. [9] Thus, given a floor are of $9\ ft^2$, the cross sectional area of the chimney was determined to be $15.42 in^2$. The air inlet holes at the bottom of the kiln near the firebox were dimensioned so that the total area for air flowing into the system equaled the area for air to flow out of the system in the chimney. [9] Thus, each air duct was given a cross sectional area of $7.71 in^2$.[2]

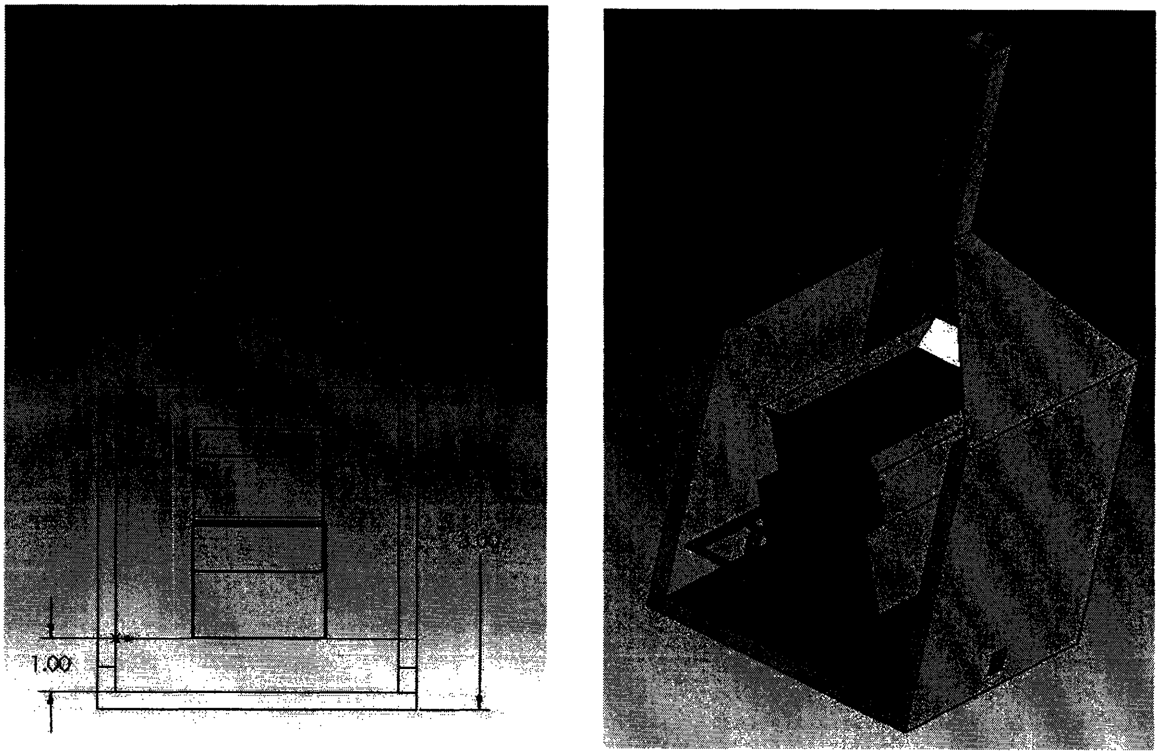


Figure 15. Schematic of Final Kiln Design with Containers Inside

---

[2] Refer to appendix for further analysis

Operation

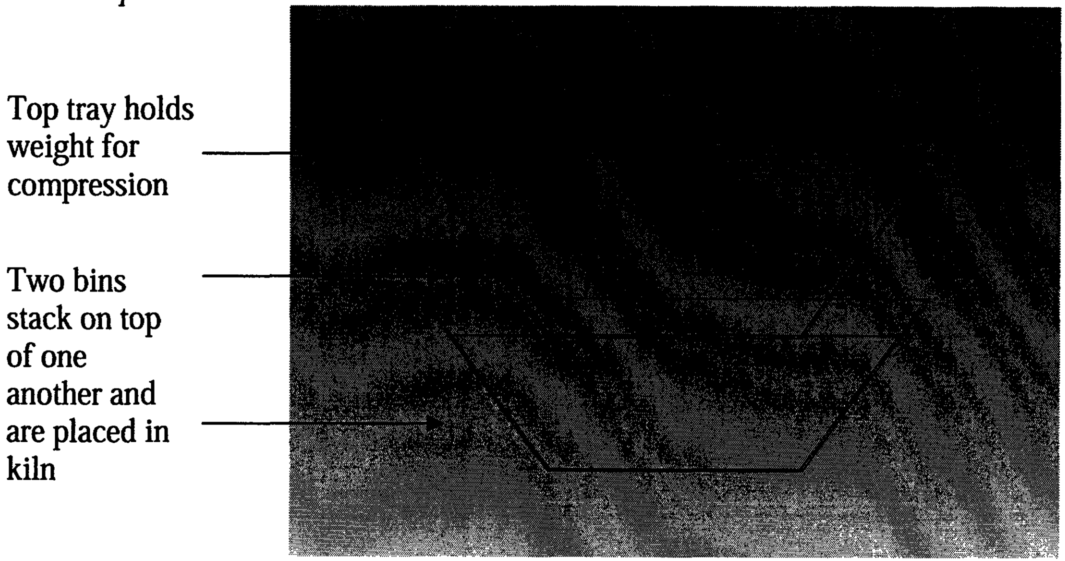


Figure 16. Schematic of stacked metal retorts

Each container will contain small holes on the bottom that allow for air flow and enable volatile gases to be removed from the material during the carbonization process.

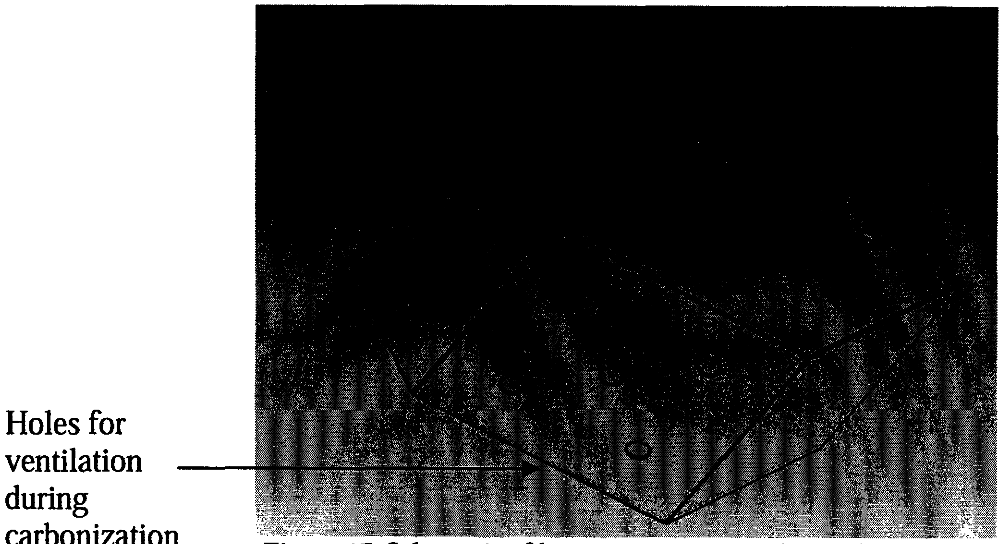


Figure 17. Schematic of bottom container with ventilation holes

The bottom container serves as the main batch that is being converted to charcoal, while the top container represents the second batch that is being dried in preparation for the second cycle. After the first cycle is complete, the bottom container will be emptied and the contents of the top container will be placed into the first container. A fresh batch will then be placed into the top container to be dried during the next cycle.

As the bagasse begins to burn and releases the moisture and volatile gases in the first cycle, the material will begin to compress due to the weight on top of the system. When the material has been compressed to its maximum percentage of the volume due to the external weight, the two containers will mesh on top of one another, preventing any further entry of air. The thinner the thickness of the container walls, the greater distance the top container will slide into the bottom container before meshing.

Top bin's movement is constrained by wall thickness

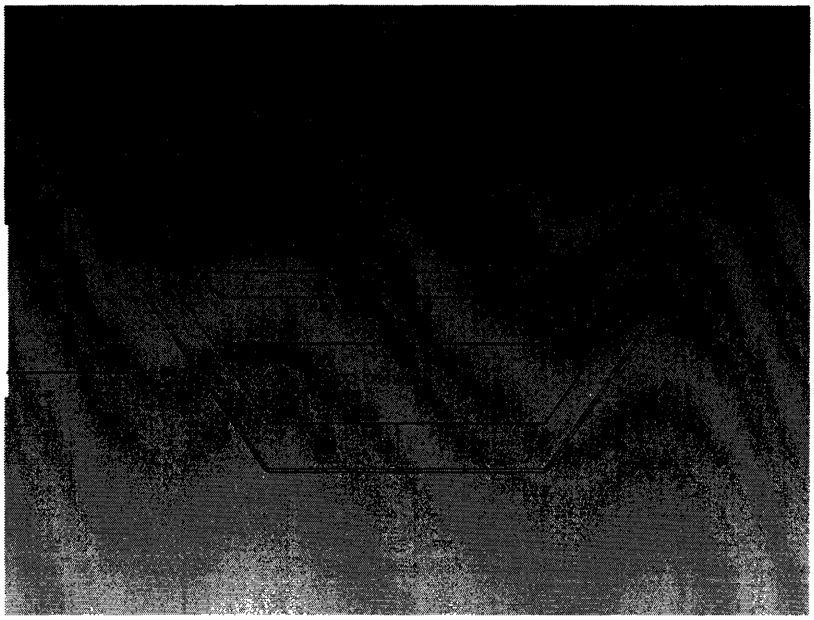


Figure 18. Containers mesh at a specified point due to wall thickness

It is at this point that the material is completely dry. This initiates the carbonization process and further release of volatile gases will occur through the holes in the bottom of the container.

4.2.2 Bench Level Experimentation

Preliminary experiments were conducted using readily available materials to determine the feasibility of the "container" concept as a method of producing charcoal. The brief experiment consisted of two bread pans and a heavy brick to serve as a weight. One bread pan was filled entirely of wood chips, which served as a substitute for the bagasse and has the necessary similarities to draw relevant conclusions. The heavy brick was placed inside of the other bread pan. The two pans were then stacked on top of one another in a similar fashion to the bin concept.

Figure 19. Bread pans stacked with woodchips and brick

The system was placed inside of a fireplace and allowed to heat up until charcoal was formed. During the process, the weight on the top pan caused the wood chips in the lower pan to compress, allowing the pans to mesh and facilitate the carbonization process. After the pans were taken out of the fire, it was observed that the wood chips had formed charcoal.

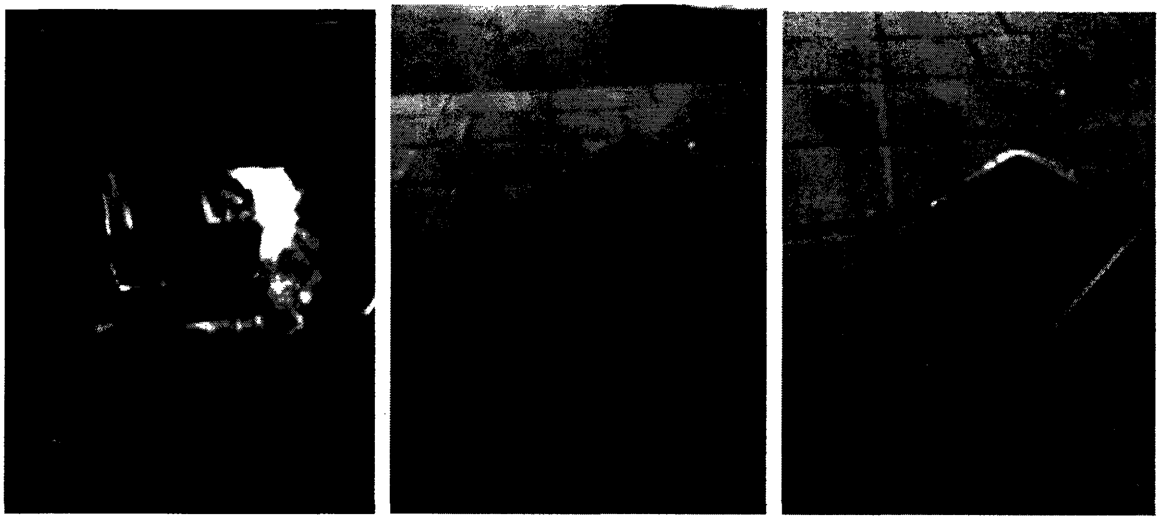


Figure 20. Bread pans placed in fire and forming charcoal

This confirmed the theory that a system of containers acting as retorts could facilitate the carbonization process, employing a compression component that aided in the carbonization and neatly packaged the charcoal inside of the container to be transported into a usable form.

4.2.3 Modules for Container Concept

Two modules were explored for the metal containers that would allow the top and bottom containers to mesh after compression was complete and prevent further entry of air into the system.

Module # 1

The first module uses two containers of identical shape and size. Because of the relatively small assumed thickness of the walls, the top bin would slide too far down before meshing. Thus, tabs on the side of the top container are placed at the appropriate location, preventing air entry when compression is complete. This appropriate location is dependant upon how much the material compresses after drying.

Figure 21. In initial configuration, a gap exists between the tabs on the upper container and the bottom container to allow for air flow to heat feedstock

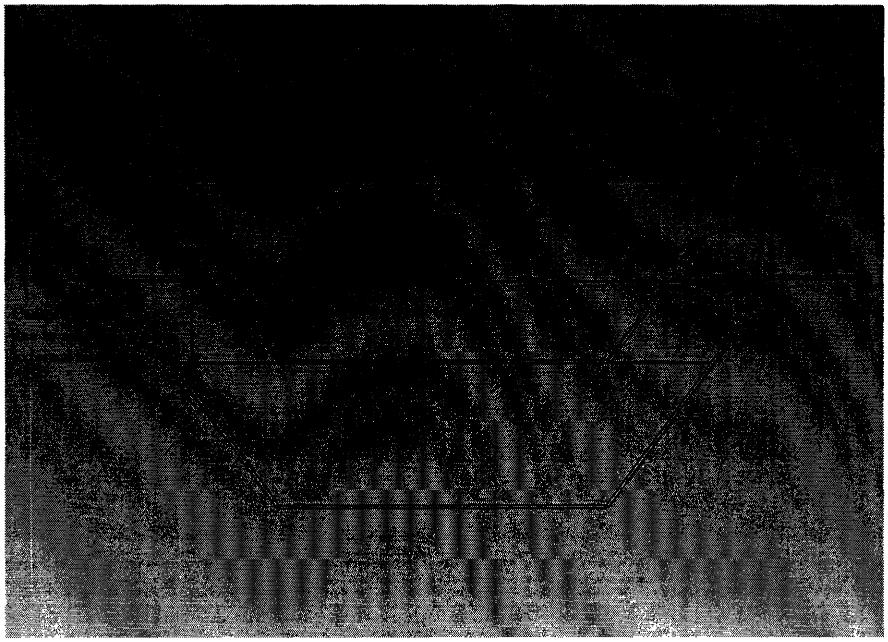


Figure 22. After compression due to weight in top bin, the tab meshes with he wall of the bottom container, restricting further air flow

Employing basic rules of geometry provide the value of the height change for a given rate of compression, which is critical for determining where to place the tabs along the side of the upper bin. For this analysis, we assume a simple geometry that will be potentially easy to fabricate and test in the future. The diagram and chart below is the result of those calculations.[3]

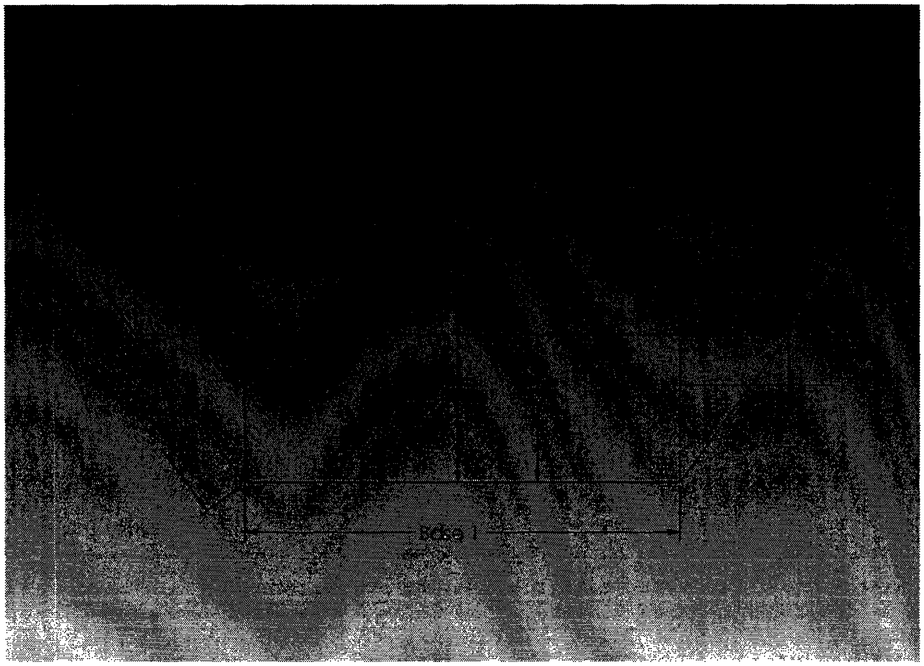


Figure 23. Dimensions used to determine height change during compression

---

[3] Refer to appendix (9.3) for detailed analysis

In this diagram $b_2 = 12; b_1 = 6; H = 4; Area = 36$

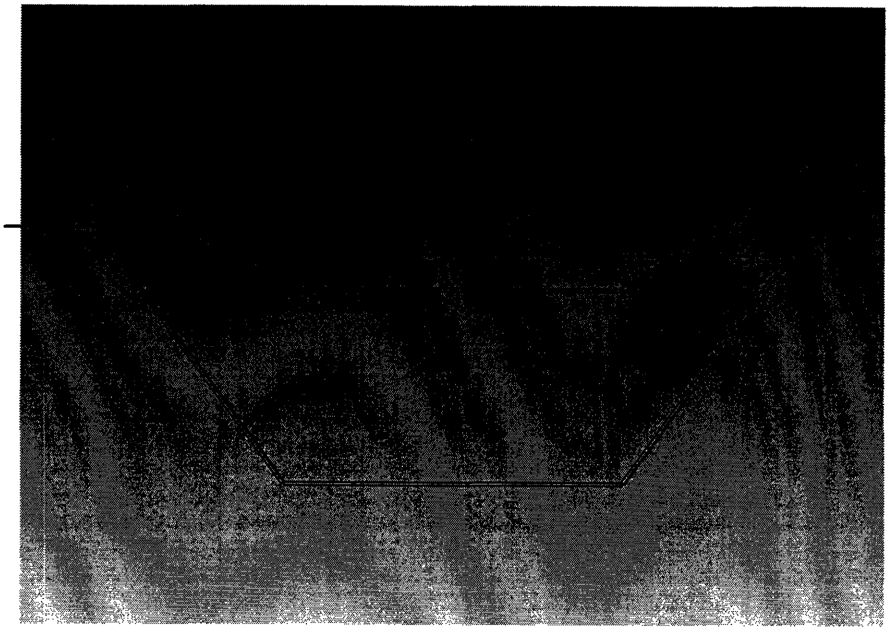
% Compression	New Area	h'	T'	S
10%	32.4	3.69	2.77	**4.62**
20%	28.8	3.38	2.53	**4.22**
30%	25.2	3.04	2.28	**3.80**
40%	21.6	2.69	2.02	**3.37**
50%	18	2.32	1.74	**2.91**
60%	14.4	1.93	1.45	**2.42**
70%	10.8	1.51	1.14	**1.89**
80%	7.2	1.06	0.79	**1.32**

Table 6. Dimensions revealing location along side wall for tabs for each compression value

Thus, for a 50% compression, the tabs need to be placed approximately 3/5 of the distance down from the top along the side wall.

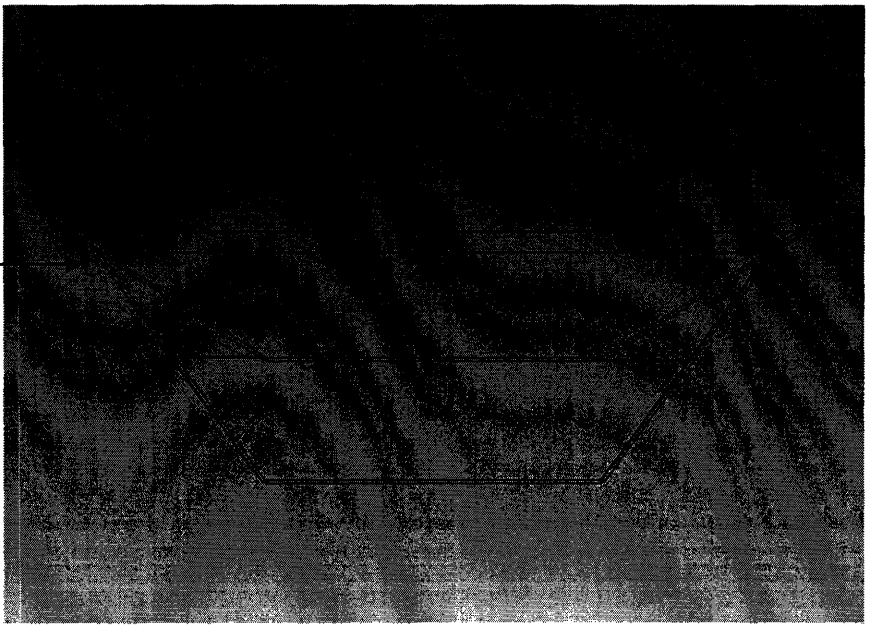
Module # 2

The second module for the container design uses two different containers shapes. The bottom container is dimensionally identical to that used in the first concept with b1=6, b2=12, and H=4. The top container has a side angle consistent with the amount of compression that occurs during the drying process. However, because there is some variability in the percentage of the material that is compressed, the angle of the side wall of the top container is also variable.



Top bin has a different side wall with a different angle

Figure 24. Schematic of containers in open position when utilizing different wall angles to facilitate meshing of walls



After a specified distance, the two containers mesh together

Figure 25. Schematic of containers in closed position when utilizing different wall angles to facilitate meshing of walls

A sensitivity analysis reveals how much the compression rate will change the angle of the top container. The analysis of the containers can be simplified by looking solely at the change in area along the side wall due to compression. This is because the depth is consistent in both containers. When the material in the bottom container is compressed, the top container moves down along the vertical axis. The side wall of the top container should be angled such that when the container moves a specific height consistent with the rate of compression, the two side walls will mesh and block air entry, as shown in the diagram above.

The height change for different compression rates was determined by analyzing the dimensions of the polygon formed from the compressed portion of the original side wall. The results of the analysis are highlighted in the following chart. (Refer to appendix (9.4) for detailed analysis)

	Dimensions of Polygon "Lost" due to Compression (Upper Bin)			
Compression	Area Lost (in^2)	Height Change (in)	Angle (Upper Bin) (θ)	Length of Side Wall (in)
10%	3.6	0.4	82°	3.03
20%	7.2	0.8	75°	3.10
30%	10.8	1.2	68°	3.23
40%	14.4	1.6	62°	3.40
50%	18	2	56°	3.61
60%	21.6	2.4	51°	3.84
70%	25.2	2.8	46°	4.10
80%	28.8	3.2	43°	4.39

Table 7. Dimensions of upper bin and associated angle changes for different compression levels

The results of our sensitivity analysis reveal that given a small rate of compression, we need a relatively shallow bin with a large side angle to allow the two containers to mesh effectively without dramatically changing the size of the top bin. While the angle only changes about 10 degrees for a 20% difference in compression, the value of the angle is too big in relation to the original container to allow a sufficient volume of material to be dried and prepared for the second cycle. Thus, in this configuration, the volume of material in each bin would be different depending on the amount of compression.

4.3 Evaluating and Selecting a Module

The previous two modules were evaluated according to the design criteria delineated earlier in the design phase to determine the best system to move forward with for testing and prototyping. The results of this evaluation process are depicted in the Pugh chart below.

Design Criteria	Module # 1	Module # 2
Integrated Steps	**0**	**0**
Simplicity (*2)	**0**	**-1 (Designing bins with appropriate angles to allow for meshing)**
Safety	**0**	**0**
Cost	**0 (Can alter the location of the tabs on the same bin)**	**-1 (May have to produce mutliple bins for different compression rates)**
Maintenance (*2)	**0**	**0**
Materials	**0**	**0**
Charcoal Quality	**0**	**0**
Total	**0**	**-3**

Table 8. Pugh Chart evaluating the two selected modules

Both systems were very similar aside from the level of simplicity and the associated costs with construction. Because of the importance of simplicity for our design, which will allow it to be more sustainable in Haiti and allow for the community to embrace the technology, the difference was slightly magnified. Module # 2, which incorporates bins with different angles matching the amount of compression in the biomass material in the container, will require different processes for making the different shaped containers and also will require more precision in the manufacturing process. This will inadvertently increase production costs, potentially above the feasible level for a developing country.

Thus, Module # 1, incorporating the tabs along the side of the bins, was chosen for fabrication and experimentation.

5. Fabrication

Module # 1 was designed for fabrication according to the dimensions chosen during the analysis for the location of the side tabs.

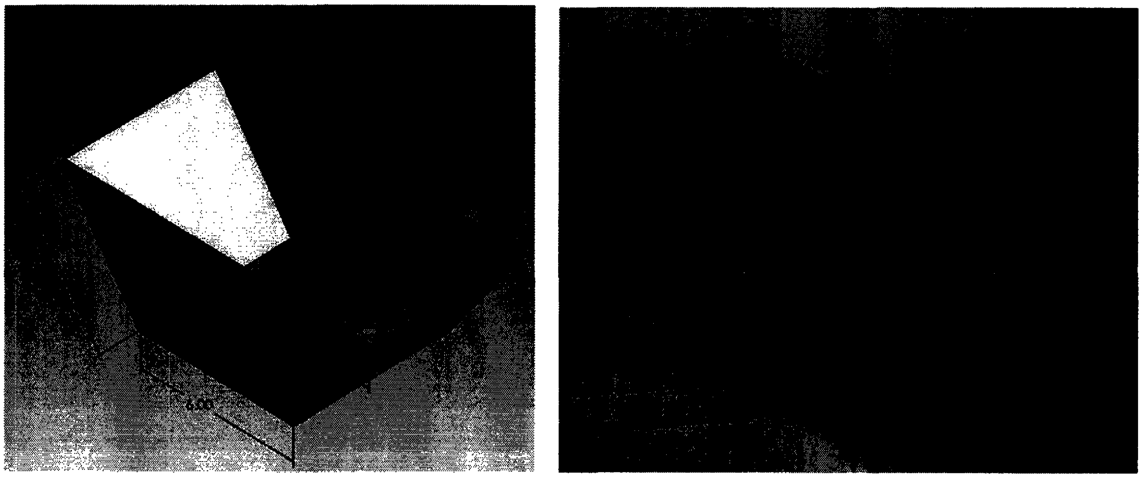


Figure 26. Prototype of bottom container

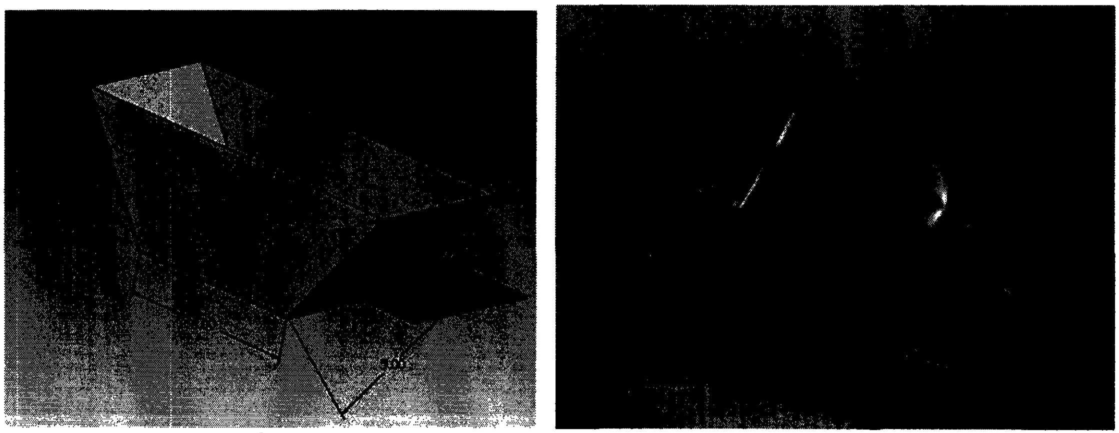
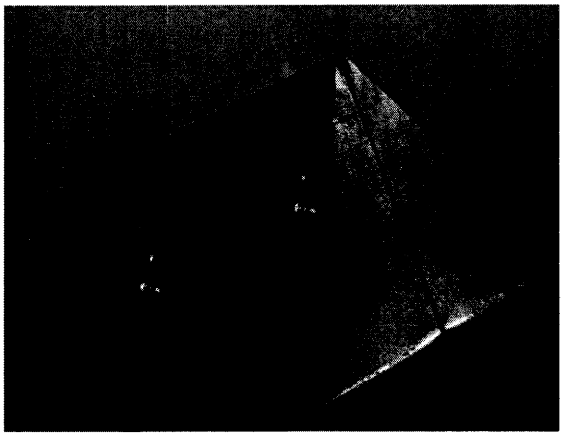
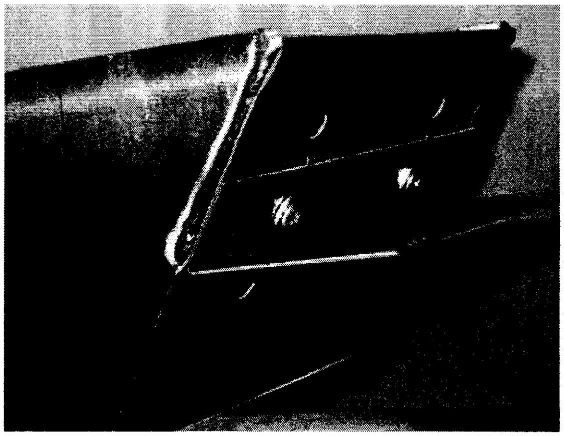


Figure 27 Prototype of top container with tabs

During testing, it was observed that air could seep through the edges of the walls. Thus, a second set of containers were fabricated without the holes on the bottom floor to analyze the significance of that aspect of the design. In addition, the top container contains various holes to test changes in compression rates.





The top container was designed to hold a brick during the experimentation process.

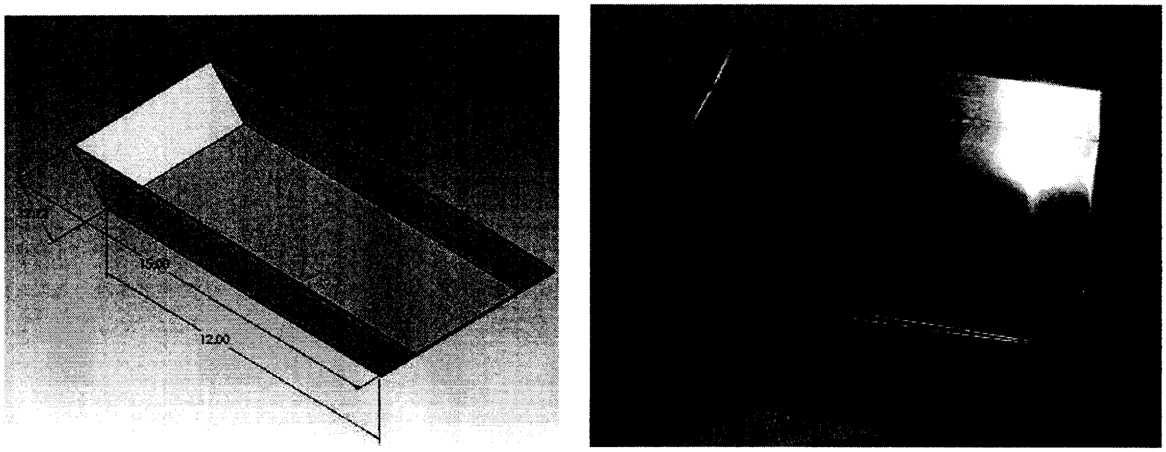


Figure 28. Prototype of top container

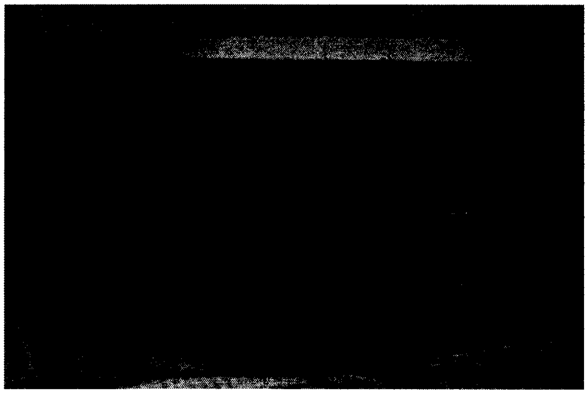


Figure 29. Final Prototype

6. Community Integration

6.1 Relevance in Haiti

Decades of management by corrupt elites have led Haiti to become one of the least developed countries in the world. The Haitian states have been ruled by a small number of educated and elite families, leaving most in dire poverty and unemployed. In Port-au-Prince, 80 percent of the city's inhabitants rely on the informal economy for survival, where they sell a wide selection of products from medicine to fuelwood to clothing. Although about two-thirds of the Haitian population lives in rural areas of the country, they receive little support from the government who favors urban industrialization over rural development. [22] They typically face a significant tax burden and consequently have complex land tenure arrangements. Unlike many rural communities in Latin America, Haitian farmland is rarely managed communally, unless dictated by development projects. The primary economic unit is the family, though sometimes neighborhood farmers will for small *gwoupman* to collectively make purchases and share labor resources to save on costs. [22] These communities could definitely benefit from an appropriate technology enabling them to collectively make use of some of their agricultural waste and sell it in the urban market.

Despite support from the international community, Haiti has been unable to shirk poverty. The international community provides 70 percent of the Haitian government's budget as well as peacekeepers to keep civil order. [22] To overcome poverty, however, Haiti must strengthen its capacity building to begin to solve its own problems rather than relying on international funding that is not being used efficiently. The poverty in Haiti has led many to exploit the natural resources that are available – most notably the forest resources - and harm the environment. Measures must be taken to strengthen democratic institutions, restore security, and protect the environment.

An economic and social development strategy in Haiti should consist of the following elements: [23]

- priority given to investment projects with social and human benefits
- clear objectives that take into account the availability of resources and ability to obtain new resources
- equitable distribution of investment programs to all regions in need
- insistence on the accountability of development groups, NGOs, and community groups during and after implementation of programs
- establishment of partnerships between grassroots organizations, the private sector, the international community, and the local government

- uphold the consistency of development programs with particular NGOs and international aid agencies

Within Haiti's political and economic context, environmental scarcities have significantly diminished the quality of life for a large part of the population. Fuelwood, in particular, is in high demand due to the weakened capacity of forests to regenerate. Wood harvesting is the primary cause of deforestation as families harvest wood for their own fuel supplies and also send wood and charcoal to the urban markets. Charcoal is the principal cooking fuel for over 80 percent of the population of metropolitan Port-au-Prince. [22] Charcoal accounts for sales worth more than US$80 million, which only a fourth returns to the rural community. [23] Thus, this project has the potential for great impact in the Haitian community and can help redistribute resources to the rural poor as well as help the environment from a global perspective by serving as model for other countries to follow.

6.2 Participatory Method

A participatory approach should be utilized to successfully implement this project in Haiti. The participatory method serves to involve the 'public' in importance decision-making processes, particularly when the 'public' is intimately connected to the project or issue being addressed. Those involved in a participatory process can include citizens, various stakeholders of a project, NGOs, and members of the government or industry. Participatory methods should be integrated into all development projects. They lead to better identification of realistic goals and measurable indicators, enable better identification of who is truly impacted by development projects, and expose the interests of the various stakeholders, thus facilitating better communicating about expectations and obligations.

Participatory methods are generally referred to as Participatory Learning and Action (PLA). [21] PLA combines a set of diagramming and visual techniques that when utilized, allow participants to better conceptualize the impact of the project or policies. In addition, PLA incorporates the principles the principles of grassroots participation to facilitate more equal power relationships. The underlying principles of PLA include:

1) Embracing complexity
2) Recognizing multiple realities
3) Prioritizing the needs of the poor
4) Grassroots empowerment
5) Promoting learning
6) Transforming knowledge into action

The first four principles focus upon empowering the poor and disadvantaged and making them an integral part of the development and assessment process. They are made equal partners in knowledge creation and problem analysis and thus, can have a more invested interest in the project. The last two principles focus upon knowledge transfer and are critical for ensuring that projects and appropriate technologies are sustainable because community member will be knowledge about how to manage the success of the program.

An important aspect of the participatory process is the integration of the viewpoints of different stakeholders to create concrete goals. PLA can help identify community dynamics. For example, PLA can help identify how a community perceives the level of poverty that exists and what elements of their lifestyle they view as most in need of help from an appropriate technology or a development program. The inclusion of a diverse group of community members can help identify the needs of women and other minorities who typically may not have a strong voice in their community.

The most common techniques in participatory processes include:

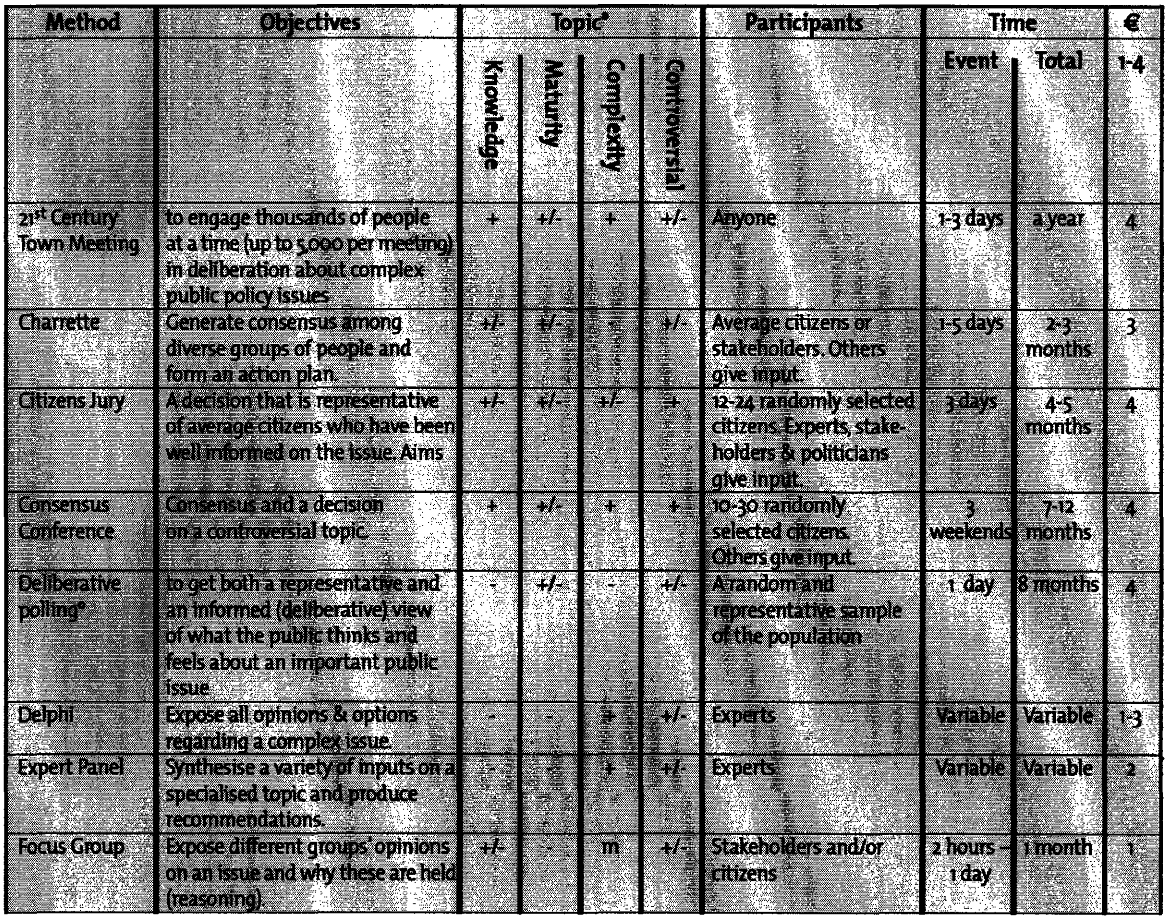
- flow and Venn diagrams
- seasonal calendars
- mapping techniques

Flow and Venn diagrams help identify linkages between different aspects of the project. It can help categorize which policies or projects are most critical and for which stakeholders. It can also help highlight the needs and interests of all stakeholders in the project and give voice to the most disadvantaged. Seasonal colanders help identify period of high work activity vs. periods of income vulnerability, which can impact how a community plans to implement an appropriate technology or integrate it into their current economy. Mapping techniques that target social and economic disparities in a community help identify how to best implement a project and enable the majority of the community to benefit. This technique can also be used to assess the impact the project yields on the community when conducted both before and after the project has been implemented.

One of the major benefits of the participatory process is the role it plays in capacity building of the various stakeholders involved in the process. [1] PLA can assist in the development of information resources and important social networks, creating a learning environment that will benefit the community far beyond the project or assessment period. The benefits can also reduce costs of project administration, reduce costs of future training programs, and attract more outside sources of funding because they can be confident in the capacity of the community to truly take advantage of the resources.

6.3 Specific Methodology for Implementation in Haiti

There are a variety of participatory methodologies that have been used successfully in a host of countries for development projects. Some of these methods are highlighted in the figure below. [24] While some methods may focus upon very small audiences, others are used by large corporations to disseminate information and brainstorm new strategies and initiatives on a global level. The methodology that seems appropriate for this particular appropriate technology in Haiti is the Focus Group method.



Method	Objectives	Topic*				Participants	Time		€
		Knowledge	Maturity	Complexity	Controversial		Event	Total	1-4
21st Century Town Meeting	to engage thousands of people at a time (up to 5,000 per meeting) in deliberation about complex public policy issues	+	+/-	+	+/-	Anyone	1-3 days	a year	4
Charrette	Generate consensus among diverse groups of people and form an action plan.	+/-	+/-	-	+/-	Average citizens or stakeholders. Others give input.	1-5 days	2-3 months	3
Citizens Jury	A decision that is representative of average citizens who have been well informed on the issue. Aims	+/-	+/-	+/-	+	12-24 randomly selected citizens. Experts, stakeholders & politicians give input.	3 days	4-5 months	4
Consensus Conference	Consensus and a decision on a controversial topic.	+	+/-	+	+	10-30 randomly selected citizens. Others give input.	3 weekends	7-12 months	4
Deliberative polling®	to get both a representative and an informed (deliberative) view of what the public thinks and feels about an important public issue	-	+/-	-	+/-	A random and representative sample of the population	1 day	8 months	4
Delphi	Expose all opinions & options regarding a complex issue.	-	-	+	+/-	Experts	Variable	Variable	1-3
Expert Panel	Synthesise a variety of inputs on a specialised topic and produce recommendations.	-	-	+	+/-	Experts	Variable	Variable	2
Focus Group	Expose different groups' opinions on an issue and why these are held (reasoning).	+/-	-	m	+/-	Stakeholders and/or citizens	2 hours – 1 day	1 month	1

A focus group is a discussion amongst a small group of stakeholders facilitated by a skilled moderator. Its design is to gather individual preferences and values on a specific topic in non-threatening environment. This seems like a great option to allow individuals from the local community to chare their concern with members of the NGO and policy makers about how they would like to see the technology integrated into their community and what needs they have. The groups can work together to redefine the technology and draft a policy that can allow its implementation to be sustainable. Some of the major benefits of focus groups include: [24]

- gauging the concerns of stakeholders on a particular issue
- determining what additional information or modifications need to be implemented for a project or technology
- obtaining input from a variety of stakeholders on the viability of a project and ideas for successful implementation

The moderator leading the Focus Group must be sure to avoid allowing any particular group from dominating the discussion and discouraging or intimidating others from sharing their opinions openly. The event should take place in a central location in the community. When all of the participants arrive, the moderator should brief them on relevant background information on the topic of discussion and inform them that the meeting is an opportunity for them to share their opinions and ideas. The moderator should lay out the ground rules for the discussion and emphasize that everyone should be given the opportunity to speak without interruption. The moderator should prepare a list of questions and ask each person to answer his questions. This will enable everyone to share their feelings and the issue and their perspective on the questions being asked. During the discussion, the moderator or an assistant can use a flipchart to record the ideas being expressed, which will demonstrate to all of the stakeholders that their ideas are important and have value in the final decisions that will be made.

The focus group exposes dissenting views that different stakeholders may have or different interests. The NGO working with the community can use this information to draft a plan that can accommodate the needs of each of the stakeholders in the program. Before implementation of the project, the NGO can present a report based on the Focus Group that highlights all of the information gathered and how the policy measures address the specific concerns of stakeholders. Depending on the nature of the project, there may be multiple Focus Groups before a report can be drafted.

6.4 Government Involvement

Due to years of corruption, many government Ministries in Haiti have a limited supply of expert personnel and seem understaffed. In addition, the Ministries have poor management records. NGOs can be instrumental in helping to provide assistance in capacity building and technology transfer; however, they must make sure to have some connection to the government. This will allow the Ministries to improve their ability to overcome the problems afflicting the Haitian community in an efficient way and promote a sense of transparency. If NGOs only focus upon capacity building in local communities without involving policy makers into the decision making process, the technology may not be successfully integrated into the Haitian economy and corruption may result in the small communities.

To address the issue of deforestation and fuel shortages, the government can provide incentives for the adoption of alternative cooking fuels, which would both limit deforestation and promote the adoption of this appropriate technology. Such a policy would require subsidizing cheap technologies, taxing fuelwood, and patrolling woodlands. [22] Another way the government can help impact policy is by providing opportunities for knowledge transfer. The development of information centers throughout communities can help educate the community on the important aspects of the development process. Lastly, the government should implement monitoring systems to assess the impact of various technologies and projects throughout the country.

7. Conclusion & Future Work

This research was successful in identifying a brick kiln system that can be utilized in Haiti to convert sugarcane waste into charcoal. Utilizing the deterministic design process was critical in identifying the most beneficial characteristics to incorporate into the design. The design is simple and can be constructed using simple materials that will either be locally supplied or provided by an external funding agency. In addition, a strategy was outline that will enable the community to be fully involved in the design and implementation process on the ground and will allow this technology to be truly sustainable for Haiti's future.

Future work must further optimize the design of the brick kiln and identify specific materials that will be used in Haiti. Experiments must analyze the impact of moisture on the charcoal yield for the various container designs. In addition, experiments must analyze the impact pressure yields on the system by testing containers with ventilation holes and containers that are completely sealed during heating. Lastly, further research must investigate the impact of air flow on the efficiency of the system.

8. Appendix

8.1 Defining System Dimensions

The dimensions of the system were determined by establishing the requirement that it be able to replace the current system using 55 gallon oil drums and maintain the same production rate. Conversion factors reveal that $55 gallons = 7.35\,ft^3$. Also, we know that the density of bagasse is approximately $7.5\,lbs/\,ft^3$.

Research indicates that oil drum kilns yield about 50% of the original volume as charcoal $(3.675\,ft^3)$. [3] We are certain that a brick kiln will be more efficient than a process using oil drums, however, specific data on how much more efficient a brick kiln is relative to an oil drum kiln is currently unavailable. We take a conservative estimate and assume that the brick kiln will be 25% more efficient than the oil drum kiln. Thus, our brick kiln system need to hold $4.9\,ft^3 \approx 5\,ft^3$ of bagasse to yield the same amount as the oil drum kilns. This volume can likely be lower due to the conservative choice for a value defining the brick kiln efficiency relative to the oil drum kiln.

8.2 Using Bagasse as a Heat Source for Kiln

In our design, we intend to utilize the heat produced by burning bagasse to serve as the energy source inside of the kiln that will both dry and carbonize the material.

First, we define the energy required to convert the water in the bagasse into water vapor. The density of bagasse is approximately $7.5\,lbs/\,ft^3$ or $120\,kg/m^3$. Most bagasse has moisture content between 45% and 55% by weight. [19] The design allows for $5\,ft^3$ of bagasse to be contained inside of the vessel, which is equal to $37.5 lbs$. If we assume moisture content of 50% by weight $(18.75 lbs)$, this percentage of moisture yields 8.5 kg of water vapor emitted during the burning process. [19]

The heat of vaporization of water is defined as the energy required to convert water to a gas. The heat of vaporization of water is equal to:

$$40.7\frac{KJ}{mol} \times 0.055\frac{mol}{g(H_2 0)} = 2.261\frac{KJ}{g(H_2 0)}$$

Given 8.5kg of $H_2 0$, we require 19,219 KJ to convert that moisture to a gas, effectively drying out the material before burning.

Next we examine the latent energy in the bagasse and determine how much bagasse we need so that it is greater than that needed to dry out the bagasse and determine if that volume is feasible for our system. Energy density is defined as the energy stored per unit mass in a material. The energy density of wet bagasse (50% moisture) is 8.2 MJ/kg while the energy density of dry bagasse (13% moisture) is 16.2 MJ/kg. [20] In our design, given the above energy density of bagasse, we require the following mass (M):

Wet Bagasse →
$$8200\frac{KJ}{kg}\times(M_{bagasse}) = 19{,}219KJ$$
$$M_{bagasse} = 2.343kg = 0.688\ ft^3 bagasse$$

Dry Bagasse →
$$16200\frac{KJ}{kg}\times(M_{bagasse}) = 275MJ = 19{,}219KJ$$
$$M_{bagasse} = 1.186kg = 0.349\ ft^3 bagasse$$

Thus, utilizing bagasse as a heat source to dry out the feedstock before carbonization requires a relatively small amount of material ($\leq 1\ ft^3$) relative to the amount of bagasse we intend to store in the chamber ($5\ ft^3$). Even with a significantly higher density due to stacking of the material, there will still be enough space inside of the chamber to increase the volume of bagasse to increase the heat and our design may not even require a the heat needed for drying all of the material because of the retort system. Regardless, the heat provided by burning bagasse will be more than enough to satisfy our needs for this functional requirement.

8.3 Velocity and Flow Rate through Kiln Design

If we take our control volume to be the vertical column of the chimney and assume steady flow through this portion of the system, then the steady flow equation becomes

$$\left(\frac{p}{\rho g}+\alpha\frac{V^2}{2g}+z\right)_1 = \left(\frac{p}{\rho g}+\alpha\frac{V^2}{2g}+z\right)_2 + h_f \qquad (1)$$

Since $\alpha_1 = \alpha_2$ and $V_1 = V_2$, the equation reduces to

$$h_f = \Delta z + \frac{\Delta p}{\Delta \rho g} \qquad (2)$$

The value for Δp is found using the formula for natural draft pressure $\Delta p = g(\rho_0 - \rho_r)h$, where ρ_0 is equal to the density of the outside air and ρ_r is equal to the density of the inside are. The density air changes relative to the temperature. In our case, the air inside of the chamber will reach a temperature of 450 °C while the air outside of the kiln will typically be at 27°C, the average temperature in Haiti. The density of air at 30°C is $\rho = 1.165 kg/m^3$ while the density of air at 500°C is $\rho = 0.4565 kg/m^3$. The value for h equals our chimney height at 4ft and the value of g is constant at $9.8 m/s^2$ Thus, we find that $\Delta p = 8.47 Pa = 0.0012 psi$.

Using the pressure differential, we can solve for the pipe head loss in equation (2) The value for Δz is equal to our chimney height of 4ft. The change in pressure is 8.47 Pa and the change in density is $0.7085 kg/m^3$. Thus, we find that $h_f = 2.4378 m$.

Using the head loss, we can calculate the dimensionless head loss parameter

$$\xi = \frac{gd^3 h_f}{L v^2} \tag{3}$$

Where d = pipe diameter, L equals pipe length, and ν equals the viscosity, which for air is equal to 7.97×10^{-5} at 500°C. Plugging in these values yields $\xi = 8.619 \times 10^6$

We now use the equation $\mathrm{Re}_d = -(8\xi)^{1/2} \log\left(\frac{\varepsilon/d}{3.7} + \frac{1.775}{\sqrt{\xi}}\right)$ to find the Reynolds number

This equation yields $\mathrm{Re}_d = 26202.14$

The velocity and flow rate follow from the Reynolds number:

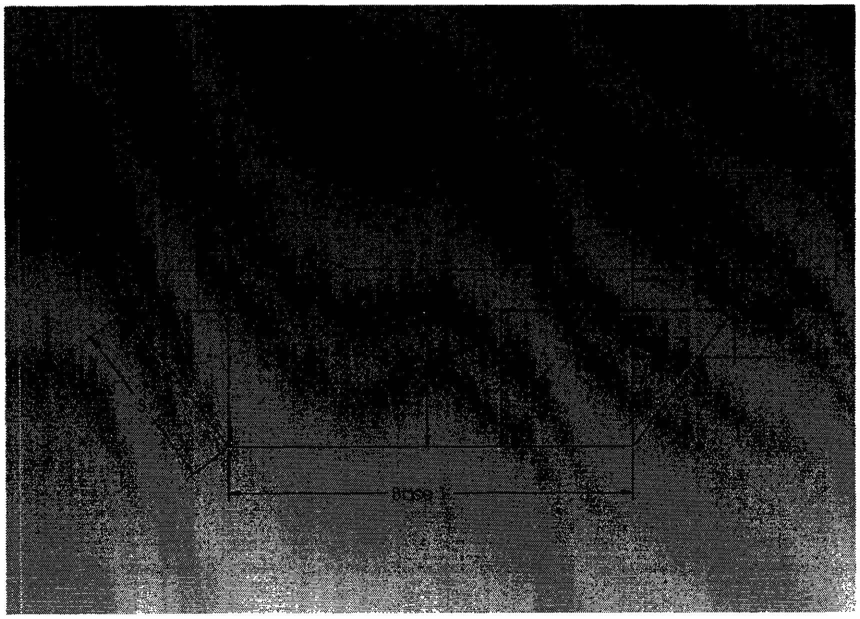
$$V = \frac{\nu \mathrm{Re}_d}{d} = 14.91 m/s$$

$$Q = V\frac{\pi}{4}d^2 = .2295 m^3/s$$

8.4 Defining location of side tab on upper bin for concept # 1

The magnitude of compression that occurs during the charcoal production cycle dictates the percentage of the original container filled with the agricultural waste. We simplify our analysis by focusing upon the area along the side wall and how the height of the material along the wall changes due to compression. The change in height can be calculated by using the formula for the area of a trapezoid. By identifying the dimensions of the piece of the area that is "lost" due to compression, the dimensions of the area along the side wall that is retained can be determined.

The area of a trapezoid is defined as $Area = h(\frac{b1 + b2}{2})$.



Given the above dimensions, we can derive the following set of equations:

$$Area = h^* \left(\frac{b1 + b2^*}{2}\right) \tag{1}$$

$$b2^* = b1 + 2T^* \tag{2}$$

$$\frac{T}{T^*} = \frac{h}{h^*} \tag{3}$$

Plugging equation (3) into equation (2) yields:

$$b2^* = b1 + 2T\frac{h^*}{h} \tag{4}$$

Plugging equation (4) into equation (1) yields:

$$Area = \frac{h^*}{2}\left(2b1 + 2T\frac{h^*}{h}\right)$$

Solving for the new height (h*) yields a quadratic equation of the form:

$$(h^*)^2 + h^*\left(\frac{b1 \times h}{T}\right) - \left(\frac{h \times A}{T}\right) = 0$$

Given experimental values of $h = 4$, $T = 3$, and $b1 = 6$, we obtain the equation:

$(h^*)^2 + 8h^* - \left(\frac{4A}{3}\right)$, where A is equal to the different area values we obtain under the various compression values. Solving for h* yields the following values.

% Compression	New Area	h'	T'	S
10%	32.4	3.69	2.77	4.62
20%	28.8	3.38	2.53	4.22
30%	25.2	3.04	2.28	3.80
40%	21.6	2.69	2.02	3.37
50%	18	2.32	1.74	2.91
60%	14.4	1.93	1.45	2.42
70%	10.8	1.51	1.14	1.89
80%	7.2	1.06	0.79	1.32

The value (S) indicates where along the side wall of the upper bin the tabs must be placed to mesh with the lower bin under a specified compression value. These values were utilized during testing to construct different experiments assuming different compression values.

8.5 Defining location of tabs for concept # 2

Based upon the definition of a polygon, we know that the $area = h(\frac{b_1 + b_2}{2})$. Given the dimensions $b_1 = 6$ and $b_2 = 12$, this equation becomes $h = area/9$. Because the only variable that changes is the height of the trapezoid in this case, the angle of the side wall of the top container can be found using simple trigonometry. We find that $\theta = \tan^{-1}(\frac{3}{h})$. Lastly, because the polygon incorporates a right triangle, the length of the side wall can be found using the equation $s = \sqrt{3^2 + h^2}$. Employing these equations, the resulting dimensions with our various area values are given in the chart below.

	Dimensions of Polygon "Lost" due to Compression			
Compression	Area Lost (in²)	Height (in)	Angle (θ)	Length of Side Wall (in)
10%	3.6	0.4	82°	3.03
20%	7.2	0.8	75°	3.10
30%	10.8	1.2	68°	3.23
40%	14.4	1.6	62°	3.40
50%	18	2	56°	3.61
60%	21.6	2.4	51°	3.84
70%	25.2	2.8	46°	4.10
80%	28.8	3.2	43°	4.39

9. References

[1] *Wikipedia.* http://en.wikipedia.org/wiki/Haiti

[2] *D Lab Project Portfolio.* http://web.mit.edu/d-lab/portfolio/sugarcanecharcoal.htm

[3] Smith, Amy. *Fuel from the Fields: A guide to Converting Agricultural Waste into Charcoal Briquettes.* <web.mit.edu/d-lab/portfolio/charcoal/Sugarcane%20Charcoal%20Manual%20Draft%20October%202004.doc>

[4] *CIA World Fact book.* https://www.cia.gov/cia/publications/factbook/geos/ha.html

[5] *Country Studies.* http://www.country-studies.com/haiti/the-economy.html

[6] Heltberg, R. *Household Fuel and Energy Use in Developing Countries.* The World Bank, 2003.

[7] AP 42, Fifth Edition, Volume I Chapter 10: Wood Products Industry. www.epa.gov/ttn/chief/ap42/ch01/final/c01s08.pdf

[8] *Biomass Technical Brief.* Intermediate Technology Development Group. www.itdg.org/docs/technical_information_service/biomass.pdf

[9] Olsen, Frederick. The Kiln Book, Third Edition. Krause Publications, 2001.

[10] Encyclopedia Britannica www.brittanica.com

[11] Antal, Michael. The Art, Science, and Technology of Charcoal Production. *Ind. Eng. Chem. Res.* 2003, 42, 1619-1640.

[12] Emrich, Walter. *Handbook of Charcoal Making: The Traditional and Industrial Methods.* Boston: D. Reidel for the Commission of the European Communities. 1985. ISBN 9027719349

[13] *Simple Technologies for Charcoal Making.* Food and Agricultural Organization of the United Nations. Rome,1987 http://www.fao.org/docrep/X5328e/x5328e00.HTM

[14] Appropriate Rural Technology Institute. http://tekdi.net/arti/content/view/42/40/

[15] CanREN. http://www.canren.gc.ca/prod_serv/index.asp?CaId=103&PgId=610

[16] Bouchette, Deb. *Packing Some Heat.* Aleatoric Art on Kiln Physics. http://www.aleatoric-art.com/Aleatoric%20Art%20(TM)%20Kiln%20Physics.htm

[17] Oliver, Lionel. *Homemade Refractories.* http://www.backyardmetalcasting.com/refractories.htm

[18] www.epa.gov/ttn/chief/ap42/ch01/final/c01s08.pdf

[19] Moisture in bagasse on small plantations in S.E Asia are reported to be 49.5%. http://energyconcepts.tripod.com/energyconcepts/bagasse.htm

[20] WoodGas. www.woodgas.com/fuel_densities.htm

[21] Mayoux, Linda. Participatory Methods. www.enterprise-impact.org.uk/word-files/ParticMethods.doc

[22] Howard, Philip. *Environmental Scarcities and Conflict in Haiti – Ecology and Grievances in Haiti's Troubles Past and Uncertain Future.* Canadian International Development Agency, June 1998

[23] *Haiti: Interim Poverty Reduction Strategy Paper.* IMF Country Report No. 06/411 November 2006 www.imf.org/external/pubs/ft/scr/2006/cr06411.pdf

[24] King Baudouin Foundation, Flemish Institute for Science and Technology. Participatory Methods Toolkit – A Practitioner's Manual. September 2005