Thermodynamic and Design Concepts Behind the Transportable Bio-Mass Gasifier

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Written for presentation at the
3rd International Symposium: Management of Animal Carcasses, Tissue and Related Byproducts
Connecting Research, Regulations and Response
University of California at Davis
Davis California
July 21-23 2009

Abstract

There are certain basic thermodynamic precepts that are used in the design of all Brookes gasification systems and to some degree these are discussed in US Patent No. 6,116,168. The Transportable Gasifier is a dual chamber system that is intended to be capable of disposing of relatively high volumes of bio-mass in an efficient and environmentally safe way. The Dual Chamber unit is an improvement on the original single chamber systems that were used in part of the UK to dispose of BSE risk material during the 30 month cull.

This paper discusses some key thermodynamic design concepts behind this technology and explains how the relatively good environmental emission results were attained. The overall geometric configuration of the gasifier, along with specific control methods for introducing auxiliary heat and combustion air are very important in creating the proper conditions for the functioning of this type of system.

Also discussed are the design issues that had to be addressed to make such a system transportable. Weight and size restrictions, along with the requirement for a relatively short timeframe for set-up made it necessary to use untested design concepts. The fact that a refractory lined unit had to be able to travel to and from the 'hot zone' also meant that a unique approach to the refractory design was required. The extensive use of ceramic fibre material was a key component in making the system effective.

A brief discussion is included on the method of loading and operating the Transportable Gasifier using a macerator and pump. The concept of linking 6 or more gasifiers to one macerator is reviewed to demonstrate how the overall capacity can be brought up to levels suitable for large volume bio-mass destruction.

Keywords. Bio-mass, Gasification, Gasifier, Transportable Gasifier.

Introduction

There is an ever-increasing need to develop, and have available, transportable bio-mass destruction systems to deal with dangerous bio-hazardous materials. With the growth in the factory farming of food animals and the potential risk of disease outbreaks, the ability to deal with such issues at the 'hot zone' has become more and more obvious. Moving infected material from an outbreak location can be a dangerous practice and it is often a logistical nightmare. The purpose behind this project is to develop a system that can be moved in quickly to dispose of large amounts of bio-mass at the site of the outbreak.

There are several major problems that must be addressed in attempting to design a large bio-mass gasifier that is transportable along main roads. The technology itself must be simple and compact, yet with the capability of dealing with large enough volumes of bio-mass to make the concept viable. Added to these issues is the requirement that the equipment should be quick to assemble and put into operation. As well, the total package must be able to operate independently of any local utilities. In most cases, the equipment would likely have to be set up in areas such farm fields, so there must be the ability to be assemble the system on uneven terrain. And finally, it is important that this system operate in an environmentally acceptable manner, essentially meeting the basic US EPA air emission and ash quality standards.

This paper describes the basic thermodynamic and physical design features that make a transportable system feasible utilizing this technology. The Brookes gasification process has proven itself with its 'fixed site' applications, but several modifications were required to meet the large volume and transportable criteria specified. It should be noted that this test unit, designed and constructed under the auspices of the Technical Support Working Group (TSWG) is the first of its kind. Future developments of this system will undoubtedly lead to modifications and improvements.

TSWG Specifications

The proposed total throughput of a complete package is 150 tons per day of deadstock and the package may consist of 6 transportable gasifiers. Thus, each gasifier would have a daily capacity of 25 tons. A Haarslev macerator and pump was included as an added feature and the intent is to link all 6 gasifiers to one macerator/pump unit. This would be the next phase of this effort, but the focus of this project was to develop one transportable gasifier capable of disposing of 25 tons per day of deadstock or bio-mass.

Thermodynamic Design Concepts

Several important thermodynamic design characteristics make the Brookes process very effective as a potential transportable unit. The following are the key features that allow this process to be compact, fuel efficient and environmentally friendly.

Heated Hearth Design

The method of using the energy of the waste mass to assist in driving the gasification process has been a linchpin feature of the Brookes process. Figure 1 (see appendix) shows a front cross-sectional view of the original single chamber style and figure 2 shows

the dual primary chamber design used for the transportable unit. Artist's sketches 1 & 2 are renderings of the side view of the single chamber gasifier in operation.

A key advantage of this design comes from the fact that the Secondary or Afterburning Chamber is immediately beneath the Primary Chamber allowing for some of the heat generated from the oxidation of the hydro-carbon fumes (entering from the waste chamber) to flow through the hearth and assist in the evaporation of the waste mass. This 'common wall' design gives the Brookes system its compact configuration plus it greatly enhances the overall energy efficiency of the gasifier. In essence, an 'energy circle' is created that partly recycles the secondary chamber heat.

Mixing Zone

An unusual feature of this system is the down-firing of the auxiliary burners which are directed into a vertical mixing zone. Secondary air is also introduced this way. The fumes from the primary chamber enter a small window at the back of the primary chamber and immediately mix with secondary air and burner heat. The mix of air and combustible gases must travel downward and turn 90 degrees to enter the first channel of the secondary chamber. This turn, with its varying velocity zones is very important in creating the high-resolution oxidation that results with this style of afterburning system.

Prior to the turn into the secondary chamber, the air and combustible gases are thoroughly mixed under very turbulent conditions. The introduction of burner air and secondary air at different velocities along with the infux of combustible hydro-carbon vapours, gives rise to a multi-vortex flow regime.

Secondary Chamber Velocity Profile

As previous discussed, the mixing zone is very turbulent. As the gases, now well mixed, enter the turn, a more predictable flow pattern is established. The corner has the effect of decelerating and then accelerating the velocity of the gases as they enter the first channel.

Generally, mixtures of combustible gases in air have flame velocities that approximate 10 feet per second. This is an important 'rule of thumb' when designing the theoretical flow velocity in the secondary chamber channel. A flame front can form when the velocity of the mixed gases is in balance with their flame front velocity and the formation of flame fronts is a key to high-resolution oxidation. Flame fronts are the best zones for initiating oxidation reactions, so creating conditions for flame front formation, even if random and unpredictable, is an excellent way to enforce oxidation of the complex hydro-carbon fumes evaporating from the waste mass.

Another very important rule of thumb is that for every 1000 BTU of energy (in most gaseous fuels), about 10 standard cubic feet of air is needed for the oxidation process. This allows us to make a simple calculation to determine the theoretical secondary chamber velocity. The actual velocity profile will be variable, but the average will be close to the theoretical value we design around.

Primary and Secondary Chamber Temperature Profiles

Graph 1 shows the temperature profiles for the primary and secondary chambers of a single chamber system. Graph 2 shows the temperature profiles for the dual chamber system employed for the Transportable unit.

Graph 1 shows that, with the single chamber units, the secondary chamber temperature is controlled at a selected set point and the primary chamber temperature rises to a peak and then falls off when the waste mass has been reduced to an inert ash residual. During the most active gasification phase the auxiliary burner input is minimal because the fumes from the waste provide most of the energy to maintain the process.

Graph 2 shows the temperature profiles for the dual chamber system. The major difference between the single chamber system and the dual chamber system is the primary chamber temperature profiles. With the dual chamber system each side is operated like two separate single chamber units, but the advantage is that the system can also be operated as a semi-continuous or continuous batch system. The transportable gasifier is operated as a continuous batch unit to allow for maximum throughput. This is made more effective by using a Haarslev macerator and pump package to pump material into the primary chambers in small, but frequent, pulses. The two primary chambers are operated 'out-of-phase' with each other to allow for the best possible energy feedback scenario. Not only is heat transmitted up through the hearth; heat will flow through the primary chambers' common center wall from the hotter to the cooler side. This enhances the gasification activity in the side that has just been loaded with a pulse of waste. In essence, with the dual chamber concept, there are multiple common walls assisting the gasification activity. The temperature in the two primary chambers never droops very far and the auxiliary burners operate at their minimum firing rate.

Primary Chamber Draft Air

Air is not forced into the primary chambers of these systems. It would be possible to push air into these chambers with homogeneous, low energy wastes, but any complex waste with potentially high energy phases can lead to uncontrollable combustion problems which, will cause emission issues. In these gasifiers the primary chamber air enters through inlet valves only by draft. The pressure in the primary chamber is slightly negative due to stack draft and a minimal amount (about 3% stoic) of air is allowed in to enhance the temperature in the chamber.

Another major benefit of allowing air into the primary chamber using only draft is that the flow velocities in this chamber are very low and as a result, negligible particulate is entrained and transmitted into the secondary chamber.

Barometric Damper

This type of draft control method has been in use for quite a long time and is an ideal way to control the pressure in this style of combustion system. These dampers are very sensitive and their control action is essentially instantaneous. Proper draft control allows for very good control over the combustion processes in both the primary and secondary chambers.

Physical Design Features

Even with the compact nature of this technology there are many issues that must be addressed to make the equipment transportable. Also, the system should be easy to set up and must to be able operate without the need of local utilities and supplies. In other words, the package should be 'stand-alone' as much as possible.

Size and Weight Criteria

There are some basic specifications for trucking in North America and to make the Transportable Gasifier feasible we stayed within the 'Wide Load' limits to avoid the need for escorts and special permits. Generally, the requirements are; gross weight of 100,000 lbs. or less; width of 12 feet or less; and height of 13.5 feet or less. A vehicle that fits these specs can travel most places in Canada and the U.S. with minimal permitting.

Compact Geometric Configuration

Most combustion systems of this nature are multifaceted assemblies that have separate primary and secondary chambers. Because of these complexities, such technologies are impossible to shrink down in size and weight to fit the trucking standards, especially when aiming for a 25 ton per day throughput.

The compact geometry of the dual chamber unit (see figure 2.) gives the opportunity to fit a large capacity system into a relatively small package. In basic terms, the gasifier body is just a rectangular steel box that looks like a large shipping container. Photos included in the appendix show the simplicity of this configuration.

Refractory Lining

Almost anyone who designs high temperature systems will advise against moving refractory lined equipment, especially after it has been cured. Beyond this concern is the weight issue. The refractory lining of such equipment is usually the heaviest part of that equipment. If anything resembling a standard lining was used in the dual chamber unit it would weigh far too much to be transportable except under very stringent conditions. To make the project feasible the refractory lining needed to be both lightweight and flexible, but with strength where required.

As shown in some of the photos in the appendix, ceramic fibre is used wherever possible. The hearth must be a high density castable and the support walls must be solid. To deal with this issue 'wide profile' insulating firebrick is employed for the support walls. Using these materials reduced the refractory weight dramatically. The approximate final weight of the refractory lined steel gasifier shell is 55,000 lbs.

Telescoping Aluminum Stack

Any system of this nature must exhaust very hot gases that are created during the combustion process. The stack must be tall enough to create the draft required to pull the gases out of the unit. For this system aluminum was chosen to reduce weight and ceramic fibre material was located strategically to prevent overheating of the aluminum. The stack is telescoping with an outer sleeve that slides over the inner section that is linked to the gasifier when the package is assembled. The outer sleeve is unlined and the

inner sleeve has only a small amount of ceramic fibre installed. The idea behind this design is simplification of the assembly procedure as well as reducing the weight and profile.

Loading Valves

Pumping material from the macerator into the primary chambers requires a top-loading configuration. To do this safely, specially designed loading valves are needed to prevent heat from rising into the upper piping system and causing serious damage. Each loading station has a gate valve that opens into a refractory lined loading valve that then opens to allow the discharge into the chamber. These valves face directly into the primary chamber and are exposed to temperatures up to, or exceeding, 1800 F.

Fuel and Electrical Requirements

The gasifier itself can be operated with two 120 volt / 30 amp supplies. The Haarslev macerator has its own generator since it uses rather large electric motors. The fuel for the auxiliary burners and the Haarslev unit is diesel because it is the easiest to access and transport. The Haarslev generator provides enough power to operate the gasifier, but separate portable generators could be provided, if necessary.

150 Ton per Day Package

The intent is to link 6 gasifiers to one macerator to allow for a throughput of 150 tons per day. This will require additional development and experimentation to resolve certain key design issues. The method for piping from the macerator pump to the gasifiers is one concern to be addressed since a great deal of flexibility will be required to handle uneven terrain problems. Another design issue relates to automation of each gasifier, and of the full package. A great deal of thought needs to go into this area because even though automation can greatly improve the efficiency, it can also be too complex for such field operations. These units could be required to function in severe weather conditions that might not be suitable for fully computerized systems.

Although 150 tons per day sounds like a large throughput, it is only a starting point. Some situations could require much greater capacity and would need several ‘6 gasifier’ packages operating 24/7 for many weeks. As development continues it is hoped that the throughput for a single transportable unit can be increased, possibly to 35 or 40 tons per day. Adding extra loading valves may be one simple answer to improving throughput, and there is also some room for increasing the overall size of the gasifier. Alternatively, there are applications for smaller versions of this system. Gasifiers that can travel on minor roads, or that can be air lifted, are certainly possibilities for future development.

Conclusions

Overall, this project involved several unique and untested design features. The dual chamber concept was new, the special refractory construction was very different from standard practice, the piping system from the macerator pump to the gasifier goes against recommendations by the manufacturer, and the operating procedures had to be developed as we moved ahead with the initial testing. Other issues such as the safe operation of the loading valves and security of the telescoping aluminum stack were also quite

experimental. In all, only one feature failed, the ash removal auger, which again was a unique and untested concept. Even with this failure the gasifier was able to function for the complete test period.

Air emission and ash residual testing by Arcadis, as reviewed and reported by Paul Lemieux of the US EPA, demonstrate that the transportable gasifier can be operated in an environmentally safe manner. The maximum throughput capability is the final aspect of this system to be determined.

This project has proven that a large, transportable, stand-alone system for destroying dangerous bio-mass can be constructed. It has also been demonstrated that such a device can be environmentally safe and very effective in eliminating pathogens from high risk bio-mass. This type of equipment can be of great benefit when dealing with serious outbreaks. Isolating a 'hot zone' and dealing with the problem at the outbreak site is much safer than having to move diseased material miles away for disposal.

References

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Brookes, D. 2000. Method of Gasifying Waste Material. U.S. Patent No. 6,116,168.

Lemieux, P. 2008. Emissions Test Report: Source Sampling for Transportable Gasifier for Animal Carcasses and Contaminated Plant Material. EPA/600/R-08/127.

Appendix

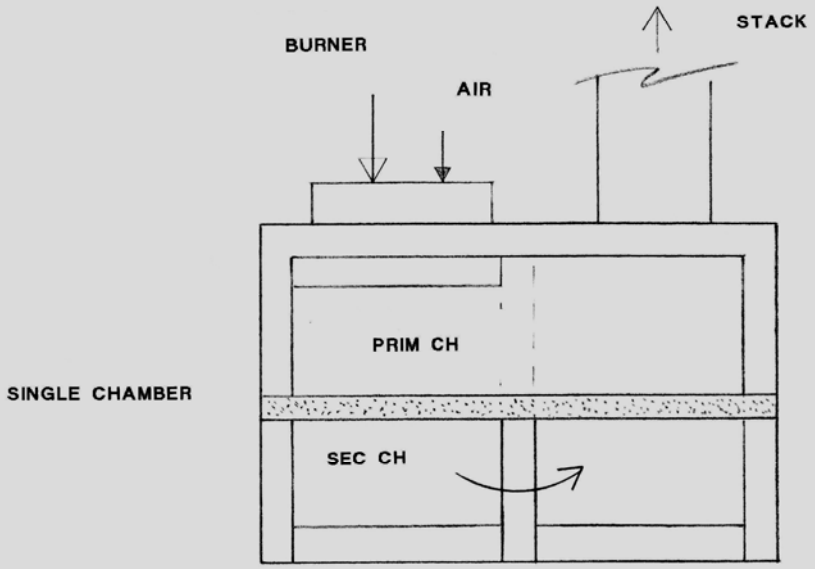


FIG. 1

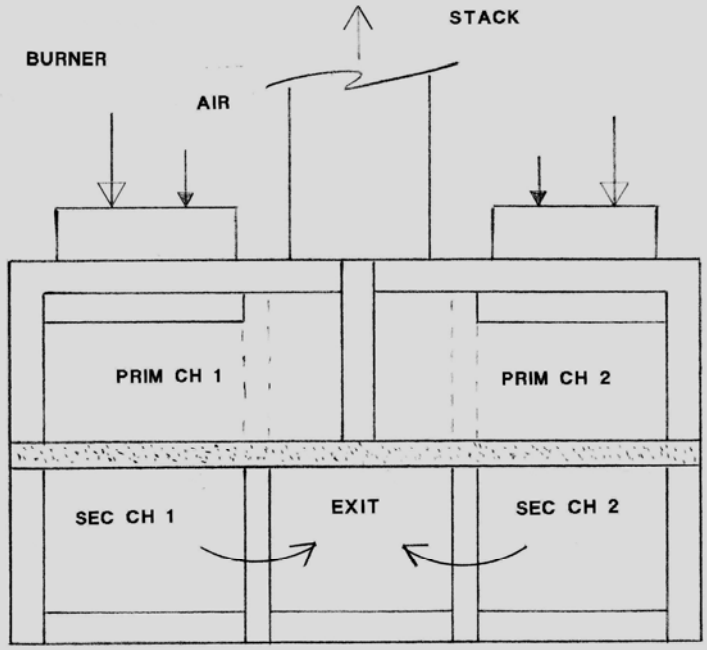
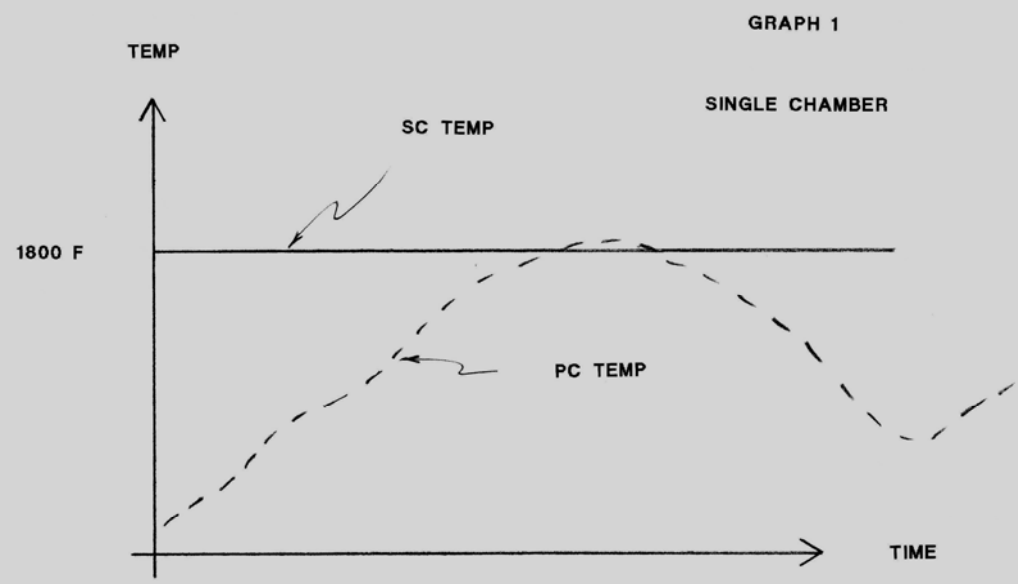


FIG. 2

DUAL CHAMBER

FRONT X-SECTS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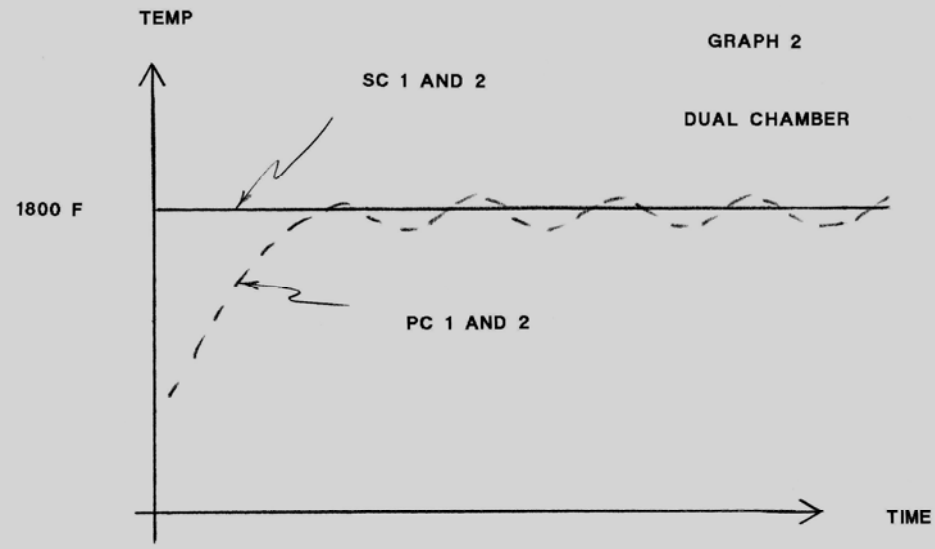
TIME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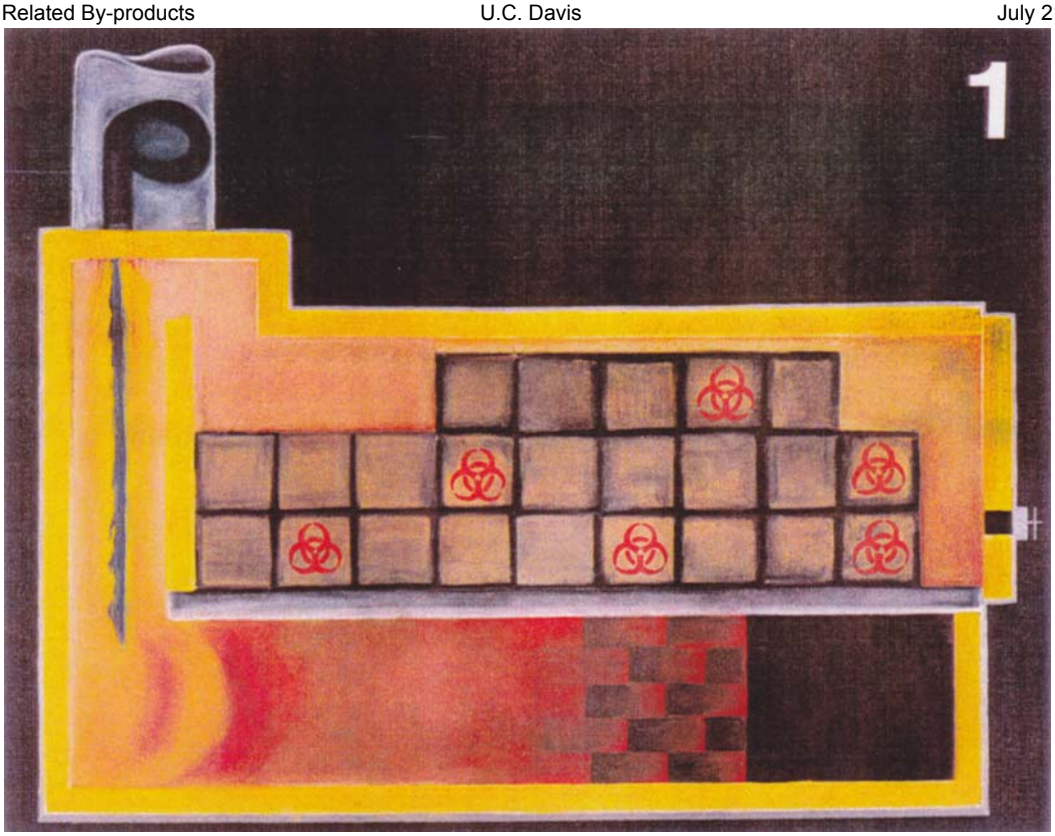

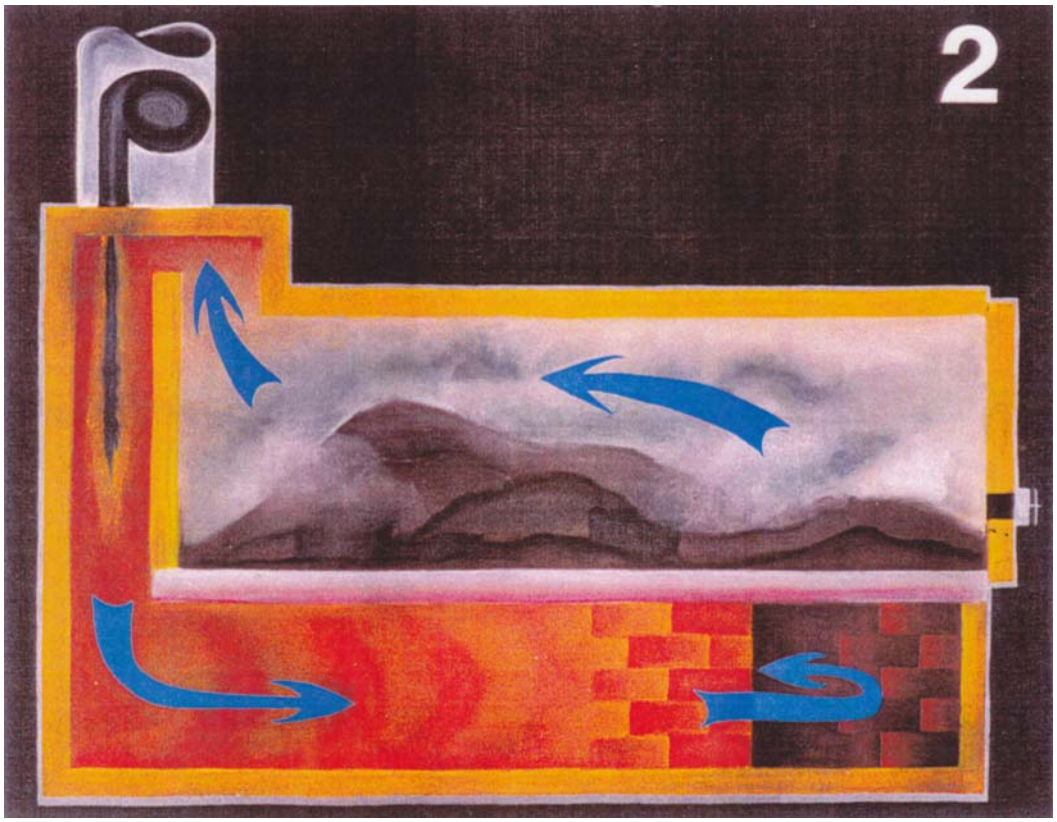

Artist Sketches

Ceramic Fibre Lining

Gasifier and Macerator Trailers

Fully Assembled Package