Design of Medical Waste Treatment Systems Employing Bioremediation
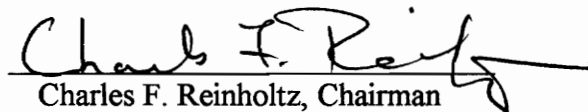
by

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Design Of Medical Waste Treatment
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by

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Abstract

The design and development of a system for disinfecting medical waste at the site of origin is presented. Investigation of the current commercial systems that accomplish this task shows that they all expose the waste to physical conditions that are harmful to all forms of life. Further, most are very expensive to install and to operate. A recently developed biochemical process promises to effectively inactivate harmful pathogenic organisms economically and without the danger of extreme heat or poisonous chemicals.

The biochemical process is not yet fully developed. Nonetheless, the development of a marketable system to take advantage of this technology has been initiated. The motivation for developing this technology and the particular system that will employ it is presented. A general overview of the system and components is presented. Previous and suggested future testing strategies are explained. Component interactions and process control are described.

ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor, Charles Reinholtz. His insight and clarity of thought have often kept this complicated project moving smoothly and in the right direction. He has also been a personal friend and a source of inspiration. I try to model myself after his example.

I must also thank Dr. Alan Kornhauser. His expertise in the areas of plant and process engineering have been invaluable. His sense of humor is equally appreciated.

I thank Dr. Robert West for his advise and understanding in the face of my short notice and sketchy communication.

Thanks especially to Mr. Clark Fuqua who conceived of this project and provided the funding to develop this system. I believe that it is an investment that will pay off. His enthusiasm for the project has kept the entire development team excited about the prospects for this technology.

I would like to thank the other members of the Bioconversions development team. This project always has been a team effort. It would have been absolutely impossible for me to accomplish this development alone. I see an amazing range of talents within the group, and believe that great things will be accomplished by every member.

Last of all, I want to thank my father. His advice and understanding kept me moving through this last semester. I earn this degree much as he did years ago. That adds to the worth of this time at Virginia Tech.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1   Project Overview

Many states regulate the disposal of medical waste, Virginia more stringently than most. Incineration is currently the only disposal method permitted by the state of Virginia. Current medical waste production already outstrips the capacity of Virginia's existing licensed incinerators. Due to a moratorium on new construction, mandated largely by environmental concerns, it is unlikely that more incinerators will be built. Further, the amount of hospital waste produced in this state is increasing steadily.

New methods are being actively sought from many quarters to allow the safe disinfection of medical waste at the hospital. Ideally, this would allow the hospital to avoid shipping contaminated material, and to dispose of the material in a conventional sanitary landfill. Most of these methods expose the material to physical conditions that are lethal to microorganisms, as well as being quite dangerous to human life. Poisonous chemicals, nuclear radiation and superheated high-pressure steam are among the most popular candidates.

A fully biological process has been developed to disinfect material by actively attacking pathogenic organisms at the micro-organic level. Certain enzymes in the presence of other non-toxic chemicals at precise physical conditions actually eat through the cell walls of all bacterial, fungal and viral pathogens tested to date. It is believed that this process, when fully developed, will be highly competitive in terms of safety, robustness and economy.

The biological process, hereafter referred to as "bioremediation," works well in a test tube on carefully inoculated strips of paper. Exposing tons of diverse material to the same conditions every day will require a fairly complex mechanical system. Restrictions presented by marketability, state law, installation and other issues further complicate the system. An iterative design effort has produced a conceptual system that overcomes these restrictions.

The design parameters, conceptual design process and a defense of the validity of the final design follow. A thorough description of the system will be given in enough detail to allow the construction of a prototype. Testing schemes are discussed, and the results of currently tested components are enumerated.

1.2   Motivation for System Development

Each year 150,000 tons of medical waste are produced in the state of Virginia. The material produced by doctors' offices and hospitals, large and small, must be disposed of in accordance with Virginia law regarding biologically hazardous material. Much of it is shipped to Virginia's few medical incinerators each day, costing health care recipients millions of dollars to cover the cost of transportation and disposal. Additional material is shipped across state lines [1, Malloy] to areas where the legislation is not as strict; a situation that cannot last forever. Incineration is now being discouraged because it is a major contributor to pollution problems. Even when equipped with scrubbers, incinerators produce ash that is carcinogenic and is therefore a serious waste disposal problem.

Ideally, safety engineers would like a system that can render medical waste harmless at the site of its production. The waste can then be hauled to a nearby sanitary landfill as ordinary household refuse. The waste would have to be rendered unrecognizable to avoid public paranoia of infectious material filling the local dumps.

The ideal system would have to pose little or no physical hazard to the operators, patients or the general public. It would have to be inexpensive to operate, preferably paying for itself shortly after the initial investment. Hospital floorspace (and headroom) being at a premium, this system would have to be fairly versatile, fitting into available space or being stationed outside the hospital.

Currently, there is an interest in new technology to replace incineration. It is unlikely that existing alternatives (Section 1.4) will be allowed to operate in the state of Virginia. A new process, developed in Virginia by Virginia institutions, stands a much better chance. The discovery of the bioremediation process could not have come at a better time.

1.3   Bioremediation -- The New Technology

Bioremediation is a word that can be defined as follows: "The remediation of danger due to hazardous waste through the application of biological agents." The bioremediation process works as follows. At the cellular level, enzymes attack the outer shell of bacteria, viruses and fungi. Enough "bites" from the enzymes crack open the cell wall, completely neutralizing the organism. Different enzymes attack different forms of cellular life. In addition, the enzyme cellulase (one of the ingredients in the bioremediation recipe) breaks down fibrous products (paper, cotton, etc.) to their individual fibers, essentially liquefying them.

This process, patented by Bioconversions Technologies, only works under particular physical conditions. A specific temperature and pH are both necessary to maximize the kill rate for the process. The actual figures are still being determined, but it is believed that the temperature must be in the 50 to 60 degree Celsius range, and the pH must be controlled to within 0.1 pH somewhere in the range of 4.0 to 6.0. Biologists are now determining whether a second set of conditions will be necessary to destroy certain viruses that are unaffected by the first. Since microorganisms are attacked individually, the success of the process must be quantified statistically. For our purposes, disinfection can be defined as a six-log reduction in biological activity. That is to say that 99.9999 percent of all organisms are destroyed. An initial population of 10^8 microorganisms will be reduced to a population of 10^2. Bioremediation is, therefore, not a true sterilization process, but a disinfection process. It should be noted that standards for incinerator "sterilization" are also based on a log-reduction in biological population [2, Lavelle].

1.4   Development Schedule

Phase I of the Bioconversions project has been the conceptual design of a bioremediation system, and a detailed design to the extent possible without actual equipment purchase. A complete conceptual design was presented in December of 1992. Most of the design details have been worked out and much of the actual equipment has been specified. This design is presented and defended in Chapter 4. Some details (Section 4.11) have not yet been accounted for. It is believed that the design is as complete as possible for this phase of the project.

Phase II of the project will entail the purchase and testing of major components specified in phase I. This work will be done concurrently with the development of control software

and the operator interface needed for phase III. All equipment needed for phase III should be purchased and tested during this phase of the work. It is believed that, not including component delivery time, this should be accomplished in the space of six to eight weeks.

Phase III will begin with the construction of a full scale bioremediation system in Randolph Hall. Components will be connected as specified in this document, and all components will be properly instrumented and controlled to perform exhaustive tests on system performance. This system will include no processing redundancies (i.e., multiple tanks) and will include only a very primitive delivery system. Eight to twelve weeks should be necessary to complete testing of the system and of the control system. Slight modifications to each may be needed.

Phase IV of the project will see a full capacity system installed at a local hospital. Operator feedback on such factors as ease-of-use, ergonomic problems and system performance problems will call for further design modifications before the bioremediation system may be marketed as a finished product. It is believed that before 1994, systems will have been installed in a number of hospitals throughout the east coast.

1.5 Competing Technology

Several methods exist for disposing of hospital waste. Not every method is approved for use in every state or for every type of waste. A discussion by Joseph Meaney [3] indicates that none of the commercially available options are entirely satisfactory for medical waste disposal. The data in Tables C1, C2 and C3 (Appendix C) is adapted from the work of Reinhardt and Gordan [4]. It suggests that bioremediation is competitive in every category. Descriptions of competing systems are given below. A more complete

discussion of their respective merits can be found in Meany [3] and Marks [5].

1.5.1 Incineration

This method of treatment destroys microorganisms through the application of very high temperatures. It can rarely be performed on-site as an incinerator is expensive. Scrubbers and other pollution-control devices compound the cost [6, Etter et al. and 7, Brunner et al.] and still leave behind ash (20% mass of the original) which is toxic and carcinogenic. Hershkowitz [8] notes that substandard on-site incinerators generate up to 3 million tons of ash every year. Currently there is a moratorium in Virginia restricting the construction of new incinerators, partially due to the difficulty in disposing of the ash. Some environmental groups have noted that items occasionally come through the incineration process without apparent damage. Paper or cloth products may appear slightly charred, but recognizable.

1.5.2 Chemical Treatment

Hypochlorite solutions are the most common agents used in these processes. The waste is shredded to some maximum size and soaked in a chemical solution for an empirically determined period of time. The solid waste is then considered safe for conventional disposal. However, the highly reactive hypochlorite solution is hazardous and is not as easily disposed of. Poisonous chlorine gas can be produced during the reaction. One installation in particular (A facility in southern Pennsylvania using the Condor chlorination system) has caused two hospital evacuations due to chemical leaks. There is a serious debate as to whether material treated in this manner is safe to dispose of in a landfill. Much of the waste has absorbed toxic chemicals which are not completely removed. Figure 1 shows the basic operation of a chemical treatment facility. Chemical bath

*Medical Safe*TEC
Z-12,500
THEORY OF OPERATION

NEGATIVE PRESSURE SYSTEM

EXHAUST FAN

HEPA FILTER

EXHAUST

MIXTURE OF CHLORINE + WATER

WASTE CONVEYOR

SOLID WASTE COLLECTION CART

WASTE

PRE-SHREDDER

HAMMERMILL

ROTARY SEPARATOR

SCREW AUGER

SOLID WASTE

SODIUM HYPOCHLORITE

SEPARATION TANK

TO SEWER
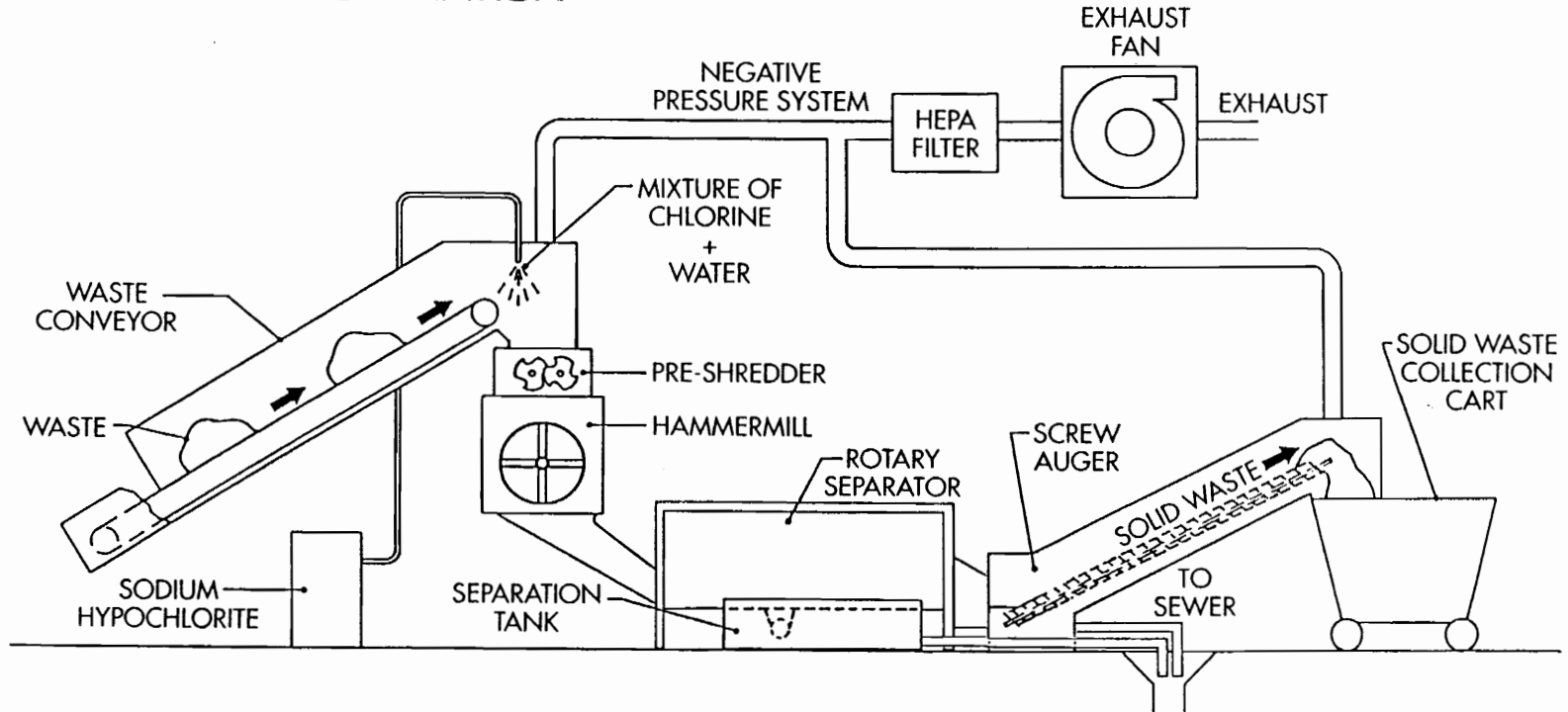
Figure 1. Commercial Chemical Treatment Facility
from "Articles and Documentation for Medical SafeTEC Waste Treatment Process"

systems are also available. A document published by Medical Safe-Tec [9] quotes a number of statistics claiming their system is both safe and effective.

1.5.3 Heating

Waste is shredded and dampened, then heated (using microwave radiation) to a temperature approaching, but not reaching, the boiling point of water. It is believed that exposure to this temperature for a few minutes will kill most microorganisms. Metal cannot be treated in this manner and must be separated out of the waste stream. Temperature is monitored only as the apparent temperature of the surfaces with which the waste comes in contact. Large quantities of liquid probably do not reach as high a temperature. ABB Sanitec, Inc. manufactures a self-contained mobile system which is in use in at least one hospital in North Carolina.

1.5.4 Autoclaving

Exposure to superheated steam for a short period of time has been shown to destroy all microorganisms including spores. Unfortunately, such a system is not practical on a large scale due to cost. Furthermore, autoclaving is effective only if every surface is exposed to these conditions. That is why laboratory autoclaves require a specific loading. It is unlikely that garbage could be "organized" such that every surface could be said to have been treated. Hershkowitz [8] suggests that large-scale regional autoclaving centers are a viable alternative to incineration, despite a 3- to 10-cent increase in cost per pound of waste processed. This is a two- or three-fold increase in absolute processing costs.

1.5.5 Radiation Treatment

Exposure to large doses of radiation efficiently destroys any and all organic activity.

Unfortunately, implementation cost for a practical disposal unit would be in the millions of dollars. Further, licensing and regulations regarding radioactive compounds make the development of such a process unlikely on a commercial scale. Little work has been done on this alternative, probably due to public perception -- that exposure to radiation can only make the problem worse. Currently, this technology is being used to sterilize food after it has been packaged. It is hoped that a more educated public may one day allow this alternative to be tested.

1.5.6   System Comparisons

Tables C1 to C3 show a comparison of currently available treatment systems based on current regulatory requirements, operating factors, cost and throughput. Bioremediation has been included with predicted factors to demonstrate that it is a competitive technology. Many of the factors listed are rather arbitrary. Those factors that merit serious attention are:

Applicability - It is unclear what the practical difference is between infectious and pathological waste. Theoretically, any system capable of sufficient disinfection should be able to handle material from pathology laboratories.

Effect of Treatment - Any system that does not granulate the waste such that it can pass through a specified screen size will not be allowed to operate in the state of Virginia.

Disposal of Residue - A system that produces other hazardous materials is at a severe disadvantage in the competition between systems.

Costs - All costs are important to a hospital when choosing a system to invest in. Operating cost is by far the most important because a difference of a few cents per pound of processed waste will add up to hundreds of thousands of dollars over the course of one year for a large hospital.

These factors have been qualitatively applied to commercially available treatment systems in Table 1. Hospitals in the Commonwealth of Virginia may soon have the option of choosing from among commercial disinfection systems to replace existing incinerators or to begin processing medical waste on-site. As was mentioned, it is unlikely that additional incinerators will be licensed in the state. Chemical hazards to operators and to hospital personnel and patients will likely eliminate chemical treatment from among the choices. The remaining viable choices include heating and steam sterilization. A final choice will be made on the basis of cost alone. It is believed that over the course of a year or two, savings in processing costs will allow the bioremediation system to undersell all of its competitors.

Table 1. Treatment System Comparison

Method of Treatment	Applicability	Effect of treatment (physical)	Disposal of residue	Operating cost (per pound of untreated waste)
Bioremediation	All infectious waste	Shredded and chemically digested	Landfill	4 cents
Chemical Treatment	Not chemical or pathological	Shredded	Toxic chemicals	6 cents
Steam/ Compaction	All infectious waste	No change in appearance	Landfill (after shredding)	6 cents
Microwave Heating	Not syringes or body fluids or pathological waste	Shredded	Landfill	13 cents
Incineration	All infectious waste	Mostly burned	Carcinogenic ash and toxic chemicals	11 cents

CHAPTER 2
CONCEPTUAL DESIGN ISSUES

The general problem discussed in this chapter is that of designing a mechanical system that will implement the bioremediation process. Safety, cost, efficiency and adaptability must all be taken into account. These factors will be discussed in detail in the following sections. It must be emphasized from the start that a "good" design is very dependent on scale. A system which is very efficient at processing the waste generated by an entire city may be inefficient or even impossible to implement when scaled to a single hospital or a doctor's office. This chapter gives some constraints and requirements for all medical-waste processing systems, and particular requirements for implementing the bioremediation system at a single hospital.

2.1   Design Parameters

It is necessary to define design parameters and restrictions when tackling an open-ended design problem such as the Bioconversions project. Employing restrictions effectively screens out otherwise effective solutions. Adding target parameters further narrows the potential design configurations as one design is better suited to a particular set of requirements. As the feasible designs evolve, it may be that certain restrictions need to be loosened, certain parameters modified. Table 2 demonstrates the selection criteria and weighting parameters which were employed in picking one good design from a number of creative alternatives.

2.1.1   Legal and Regulatory Restrictions

A number of state and federal regulations exist pertaining to the safe handling and disposal of medical waste. A discussion of the pertinent federal regulations regarding medical

Table 2. Selection Criteria

Screening and Weighting Parameters	Breakdown	Weight (max score)	Comments
Absolute Height	• Without delivery system • Of delivery system	15 5	10-foot ceiling requirement for general design. Delivery system customized for each hospital.
Reliable Size Reduction	• Mean particle size • Variance	10 10	Maximum allowable particle size is about 0.5 inches Some deviation above this mean size is acceptable
Throughput		20	Estimate of system performace in pounds of untreated waste processed per hour.
Operating Cost	• Labor • Utilities • Hauling • Materials • Maintenance	3 5 3 5 4	See Appendix A for an example of operating cost breakdown.
Capital Cost	• Delivered part • Installation cost • Installation time	10 7 3	Only component cost can be accurately predicted at this time.
Floorspace	• Total Area • Adaptability	5 5	A design that can efficiently use floorspace in an oddly shaped room is valuable.
Robustness	• Number of uncertainties • Severity of uncertainties	10 10	Any unknowns regarding system performance or reliability must be accounted for.

waste and their relative effectiveness can be found in [10] and [11]. Current Virginia Commonwealth regulations [12] that are especially pertinent are as follows:

1.) Medical or Hospital waste shall not have its appearance altered before sterilization or disinfection treatment has begun.

2.) Medical waste may be disposed of only by incineration or autoclaving in the Commonwealth of Virginia.

The first of these regulations was originally passed to prevent unscrupulous persons from simply rendering the waste unrecognizable, then hauling it to the dump. The spirit of the law can be upheld by demonstrating that size reduction is not done before treatment, but is actually a necessary first step in the treatment process. It was at one time thought that this regulation could be followed to the letter (refer to section 2.3.1). This has been shown to be uneconomical and impractical at best.

The second restriction is, of course, something that cannot be designed around. The sponsors of this project are counting on a new policy in Virginia that will allow hospital waste to be disposed of by other means. Dr. Jack Keene of the Medical College of Virginia is currently working with the Virginia Department of Waste to revise those documents regulating medical waste treatment to allow "disinfection" instead of sterilization as a valid method of disposal.

Other restrictions involving the potential dangers of operating machinery and of being in proximity to pathogenic material are regulated by state and federal agencies. In order to simplify the licensing and validation process, the operator has been almost entirely designed out of the proposed system. There is no reason for a human being to be especially close to any of the components during standard operation. Subsystems with

which the operator must come in contact have been made as safe and foolproof as possible. The computer/operator interface will be designed to immediately take steps to curb dangers detected by the system and to clearly instruct the operator as to the necessary steps that must be taken to insure safety.

2.1.2 Self-Imposed Restrictions and Target Parameters

We require that material processed by the system be shredded down to a maximum size of about 0.5 inches in the largest dimension. This will allow all surfaces to come into contact with the treating fluid, and will also render the material unrecognizable after treatment. This is considered a major benefit in terms of public perception and marketability. In the state of Virginia, this is also a legal requirement. New laws being developed in Virginia specify the allowable size of destroyed medical waste. The Bioconversions development team (including the author) has assisted in defining these size requirements to ensure that they can be met using available technology.

The final system must be able to fit into a room with a ten foot ceiling. This restriction has been imposed because many hospitals with low ceilings will want to install the system into existing space. Further, the desired option of placing the entire system in an enclosed tractor-trailer dictates a fairly low profile (maximum 11 feet).

Operating costs per pound of waste must be below that of competing systems. Only competing technology that is currently being used has been researched to determine target operating costs for the system.

Capital cost must be kept to within a few hundred thousand dollars. An original target of

$100,000 proved to be impossible for any reasonably robust and effective system. A target cost of $250,000 after installation is now being pursued. Table 3 estimates the costs of competing systems as ranging from $350,000 to $2,000,000. The newly designed bioremediation system must be competitive in terms of initial investment. It is believed that after installation costs, overhead and profit have been included, the bioremediation system will cost three to four hundred thousand dollars.

A target throughput of five thousand pounds of waste per day (one shift) was chosen because that is the approximate daily production of waste by a mid-sized hospital. Roanoke, Virginia Memorial Hospital, one of the hospitals under consideration for a trial installation, produces 2 to 3 tons of infectious waste every day. Much larger hospitals, up to three thousand beds, have the option of running a single system through three shifts. A mid-sized (1000 bed) hospital was chosen as a target for the simple reason that there are more of them: 6 in Virginia and nearly 200 in the United States. The potential market in large or small hospitals is less certain. Often, smaller hospitals or clinics will ship their waste to larger medical facilities for treatment and disposal.

A "footprint," or total necessary floorspace, has not been determined, as an adaptable system was seen to be more desirable than a smaller, unadaptable one. It has been a useful guideline to try to insure that every system could fit in the back of a tractor-trailer rig (Figure 2). Because of the space shortage in most hospitals, it is desirable to have a system that can occupy any available space.
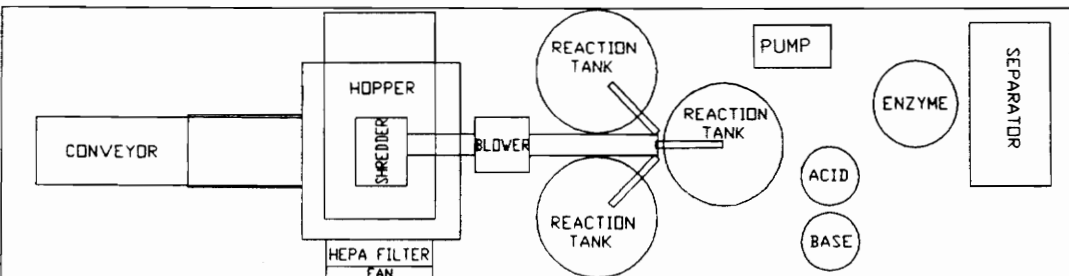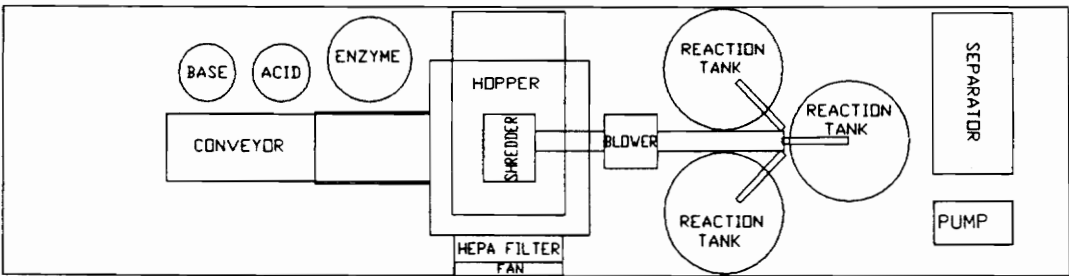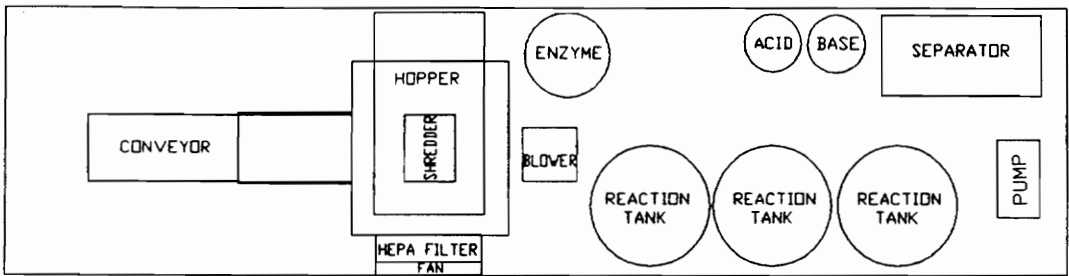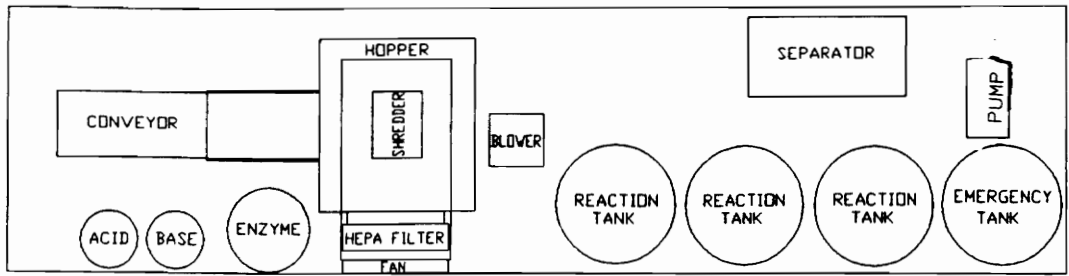
Figure 2. System Floorplans in
10 ft x 40 ft Trailer Enclosure

17

2.1.3 Safety Restrictions and Regulations

Airborne pathogens must not be allowed to escape from the system once the waste has been delivered. Any potential openings, crevices or vents to the system interior must be at a state of negative pressure wherever there is the potential for hazardous material to escape.

The system must be designed in such a way that any necessary maintenance can be performed without risk of exposure to infectious material. Allowances must be made to disinfect any and every component that might conceivably need standard or emergency maintenance.

Pressure vessels and boilers are under especially stringent safety regulations and have been deemed undesirable for this application. Any industrial machinery that may pose a hazard to the operator must be interlocked in such a way that the operator cannot be injured accidentally. The risk of leakage of any chemicals or agents that may pose a health hazard must be eliminated. Any agents, liquid or otherwise, which may cause an allergic reaction must also be contained.

2.1.4 Physical Process and Installation Parameters

As mentioned, material must be taken from its initial state (usually in bags or boxes) and granulated to a size of approximately 0.5 inches [13]. The material must then be exposed to a solution of hot water (50 degrees Celsius) and various enzymes and a pH of about 4. A second pH in the very alkaline range may then be necessary. The actual system must be flexible enough to allow for changes in the process as the biological reactions become better understood.

The slurry must be agitated at a controlled pH and temperature for about two hours to thoroughly disinfect it. All materials (with the possible exceptions of metal and glass due to their smooth surfaces) must be vigorously agitated for the entire two hours to promote enzyme transfer from surface to surface.

Liquids and solids must be separated after the disinfection process has run to completion. It is expensive to transport wet material (hauling cost being proportional to weight), and landfills generally will not accept material that is wet. As a rule, the material must pass a wetness test to be acceptable for landfill disposal. It may be desirable to reuse the liquid after separation for its chemical and heat content.

The installed system should use only those utilities immediately available in a mid-sized hospital. This will include electrical power, hot water and small quantities of live steam. Natural gas or oil as well as large quantities of live steam are not available (or are difficult to obtain) at many hospitals, and so shall not be considered as available resources for this system.

2.2   Materials

2.2.1   Materials To Be Processed

Nurses and housekeeping personnel collect pathological waste (tissue, body fluids or lab cultures) and infectious waste (material that is at high risk of transmitting a disease) from surgery, laboratories and patients' rooms constantly. This material is placed in approved marked containers (see below) and carried to an on-site storage facility daily. Infectious waste may be stored at room temperature for 72 hour before treatment becomes mandatory. Refrigerating the material allows a storage time of 7 days, and freezing allows

30 days. Low-temperature storage laws [13] do not necessarily apply to pathological waste, which is usually kept separate from infectious waste.

One advantage that the new technology has over existing disinfection systems is that there is no need to separate material out of the waste stream. Any material which the hospital has deemed potentially infectious is "redbag" waste, so called because it is placed in sturdy red plastic bags labeled as biohazards. As indicated in Table C1, there are systems that cannot process metal, chemicals, material from pathology laboratories, etc. It has been understood from the beginning that no separation of waste would be included in the operating procedures for the proposed system. The system must be capable of shredding or grinding any material that might be found in a hospital waste stream. The only allowance made was that knee or hip replacement joints, consisting of about a pound of titanium-steel alloy, would not be part of the waste stream. This case should not require separation because these items are never placed with "redbag" waste [14].

The contents of an average redbag include a large quantity of paper and fibrous products from surgery (e.g., gauze, wipes, bandages and masks and caps.) All disposable medical instruments are found in redbags, including syringes, scalpels and suture kits. Many other products commonly associated with doctors' offices must be processed. Add to this list the constituents of ordinary household refuse which is collected from patients' rooms. Some of the extraordinary articles which must be processed as redbag waste include prosthetic limbs, human tissue and bone.

At this point, it is unknown whether large quantities of housekeeping chemicals (i.e., cleaning agents) will significantly affect the biochemical process. However, it is believed

that nothing that could conceivably enter the waste stream can physically damage the apparatus.

A word must be said about consistency. A congressional report on the material breakdown of infectious hospital waste suggests that an average redbag contains (by weight) about 60% paper, 30% polymers/synthetics and 2% metal with the rest (8%) being glass, cloth, human tissue, chemicals, etc. The process characteristics were determined with this in mind. A severe variance from this breakdown (i.e., 80% metal) may seriously effect the process. It is believed that even the severe case of 100% metal would be effectively shredded and soaked. Whether the material would be agitated is a difficult question. It has been suggested that a load consisting largely of liquid and non-absorbent material would incapacitate the conveying system. Such bizarre loading could have detrimental effects on the process components and must be avoided. In this sense, some control of the waste stream is necessary. It will be shown later that testing can determine the limits at which the system can function effectively.

2.2.2   Materials of Construction and Fabrication

Thought must be given to the materials from which the bioremediation system will be constructed. Because of the constant presence of moisture, high temperatures and oxidizing agents in the reaction tanks, it is deemed prudent to allow only corrosion-resistant components in the system interior. Stainless steel tanks, piping and valves are to be used wherever liquid may come in contact with the surface. Further, much of the system may be periodically exposed to live steam in order to decontaminate them for inspection and maintenance. All surfaces including, for example, fan blades, hoppers, shafts and seals must be of material that can survive this sort of treatment.

2.3   Single Volume Vs Parallel Process

From the outset, it has been recognized that there are two main configurations that the system could take. A schematic diagram of both of these is shown in figure 3. Each of these is very general and allows a great deal of variability in sequence, component choice and physical configuration. Each configuration has a number of distinct advantages.

2.3.1   Single Volume

The single volume configuration can most easily be thought of as a "washing machine" or "blender" system. Material is placed into a single volume in the form of boxes or bags of waste, and later removed either as a disinfected slurry or as a dried mulch of already separated waste. All the necessary operations occur within this volume:

- Opening the bags/boxes
- Shredding the material to 0.5 inches
- Adding the required amount of treatment solution
- Agitating the material for two hours
- Separating (possibly) the solids and liquids

This actually does sound quite a bit like the operation of a kitchen blender or a commercial washing machine, in which material is soaked and agitated, then spun dry and removed.

PARALLEL PROCESSING STRATEGY

CONTAINMENT DUE TO BIOHAZARD

```
                              ┌──────────────┐
                              │  REACTION/   │
                              │  PROCESSING  │
                              └──────────────┘
┌──────────────┐   ┌──────────┐  ┌──────────────┐
│ SOLID WASTE  │──▶│   SIZE   │─▶│  REACTION/   │───▶
│  DELIVERY    │   │ REDUCTION│  │  PROCESSING  │
└──────────────┘   └──────────┘  └──────────────┘
                              ┌──────────────┐
                              │  REACTION/   │
                              │  PROCESSING  │
                              └──────────────┘
```

LIQUID TO SEWER ◀── **SEPARATION** ◀──

SOLIDS TO COLLECTION BIN

SINGLE VOLUME STRATEGY

CONTAINMENT DUE TO BIOHAZARD

```
┌──────────────┐   ┌────────────────────────────────┐
│ SOLID WASTE  │──▶│      ALL UNIT OPERATIONS:       │
│  DELIVERY    │   │                                │
└──────────────┘   │       BAG/BOX OPENING          │
                   │       SIZE REDUCTION           │
                   │     REACTION/PROCESSING        │
                   │                                │
                   │     (POSSIBLY SEPARATION)      │
                   └────────────────────────────────┘
```

LIQUIDS TO SEWER ◀── **SEPARATION?** ◀──

SOLIDS TO COLLECTION BIN

Figure 3. Block Diagrams of Single Volume
and Parallel Systems

23

Such a system would be less prone to the inadvertent release of pathogens into the environment. All operations take place within the single volume, and every surface in that volume is subject to the bioremediation process. The area through which leaks could occur is fairly small and easy to contain. By the same token, the footprint of such a system would be reasonably small.

It was originally thought that the cost of such a system would be low. Two or three main components, each performing a number of tasks, could accomplish all the operations. For instance, bag opening, material shredding and agitation could all be accomplished with a single large blade (Figure 4). Perhaps by rotating the volume about a horizontal axis, agitation and separation could each be accomplished (at different speeds).

Only a thorough investigation of available components showed this concept to be unacceptable. The system could not be made efficient, therefore the operating costs were high. A single system capable of the necessary 3-ton per day throughput could not easily be designed under the ten-foot ceiling restriction. Further, no "blender" type agitator could be shown to uniformly reduce the waste size to something less than the required 0.5 inches. It must be noted that a system of this nature may be perfectly acceptable for very small or very large throughputs. It is unfortunate that it does not lend itself to our immediate application.
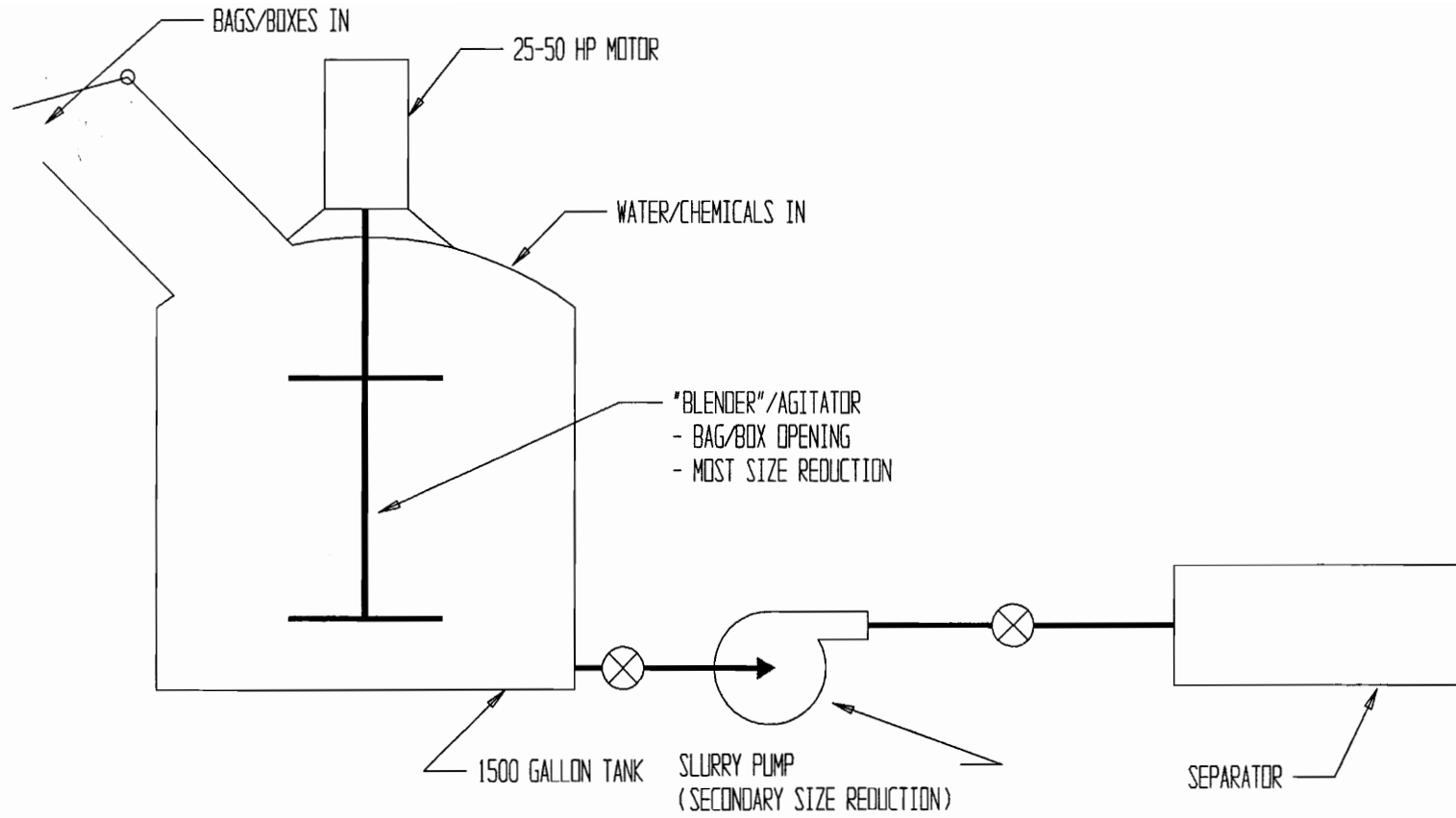
Figure 4. Possible Implementation of Single Volume System

2.3.2 Parallel Process

Many of the treatment operations mentioned above are similar or identical to standard unit operations in a chemical process plant. It is no wonder that some of the first conceptual sketches of what the system might look like showed material being conveyed from station to station, undergoing some operation at each station. It was quickly realized, however, that the two-hour biochemical reaction was a serious bottleneck in the system, causing most of the system components to remain idle for the majority of the operating day. A large grinder capable of quickly filling a tank with the required amount of solid waste would run furiously, then sit idle until that tank was again capable of accepting waste.

The serial block diagrams (Figure 3) now branch from a single trunk, then reconverge to a single process. This allows the same throughput to be accomplished with continuously running components that are much smaller in capacity than would be required for a single-line system. As an example that will soon become familiar, a single shredder with the necessary total daily throughput can run continuously, the shredded material being conveyed to whichever process tank has room. The shredder then becomes the limiting factor, and the smallest shredder that can accomplish the necessary throughput can be specified. Power requirements and component size of most components drop substantially. Further, it saves the equipment some wear and tear in running continuously; a large number of starts and stops can damage some types of process equipment.

Disadvantages of the parallel tank concept include size, complexity and material conveyance. It becomes necessary to transport material (shredded waste) from station to station in a variety of forms. Material that was shredded must be transported to a reaction tank, then later transported at a substantially different consistency to a separator. The

system begins to look less like a machine and more like a scaled down chemical plant. Piping, ductwork, vents and valves have become external components to control the flow of air, liquid, slurry and solids throughout the system. Although this allows us a number of variables with which to reduce operating cost, it gives the system a rather large footprint, though of adaptable nature. All this piping and ductwork becomes a safety issue, as a leak in any area could conceivably leak infectious material, liquid or oxidizing agents to the surrounding environment. Intuitively the parallel process category is not as inherently safe.

The greatest single advantage of the parallel process concept is that it is feasible within the given design restrictions. Operating cost is very low, capital cost reasonable, and the system can be made to fit an arbitrarily shaped room with a ten-foot ceiling. In addition, the failure of a single component (tank, valve, agitator, etc.) does not necessarily shut down the system. Throughput may be reduced, but the parallel process system is actually quite robust.

CHAPTER 3
General Design of Medical Waste Bioremediation Systems

3.1 Theory of Operation

The parallel processing system consists of four sub-systems: delivery, size reduction, reaction and separation; and three peripheral systems: metering, control and disinfection. The delivery system, or front-end, accepts unprocessed bags or boxes of medical waste, and transports them to the size-reducer. The size-reduction system physically alters the waste into small particles. Biochemical reactions then take place to inactivate all organisms present. The separation system removes most liquids from the slurry and delivers the dried and compacted material to a garbage collection bin. The entire process is monitored and controlled by a central control system. The metering system transports chemical and biological components to the reaction slurry, and the disinfection system cleans the rest of the assembly at the end of each day. Inter-system components such as valves, pumps and conveyors will also be discussed. Figures 5, 6 and 7 show schematics of several systems that were considered in the preliminary design stage. Figure 5 shows that the concept of a single-volume treatment system was not abandoned until cost and lack of available components indicated it would not be practical. Figure 6 clearly indicates the separation of discrete systems once the bags have been delivered. Figure 7 is a schematic which eventually developed into a complete design. The evolution of that concept led to the final bioremediation system which will be described in detail in Chapter 4.

BAGS/BOXES IN

JAYCO DISPERSION MIXER

(2 AGITATORS)

RECIRCULATION LOOP

SEPARATOR

1500 GALLON TANK

WATER CHEMICALS

VAUGHN CHOPPER PUMP
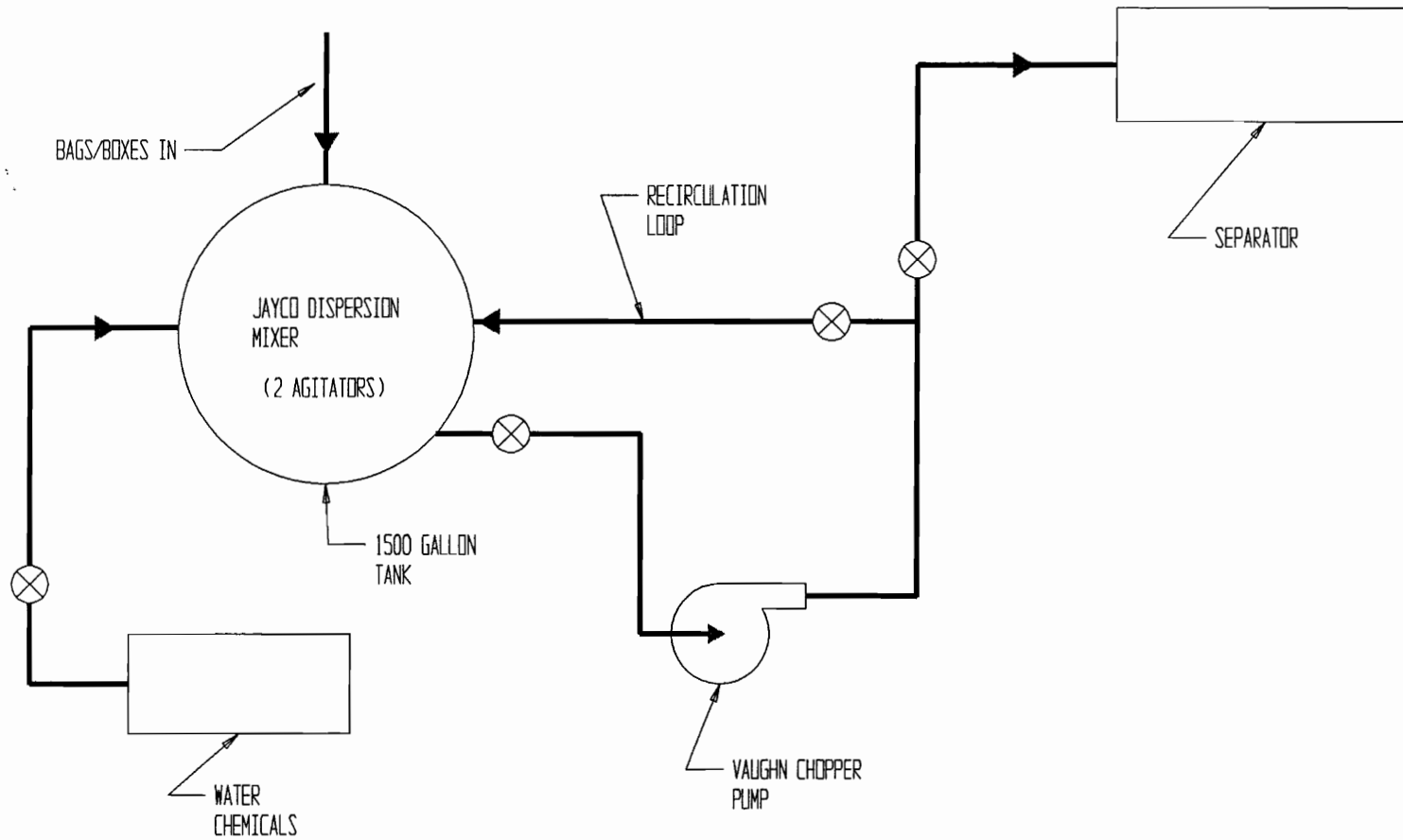
Figure 5. "Buzzsaw" Single Volume System with Solids Recirculation
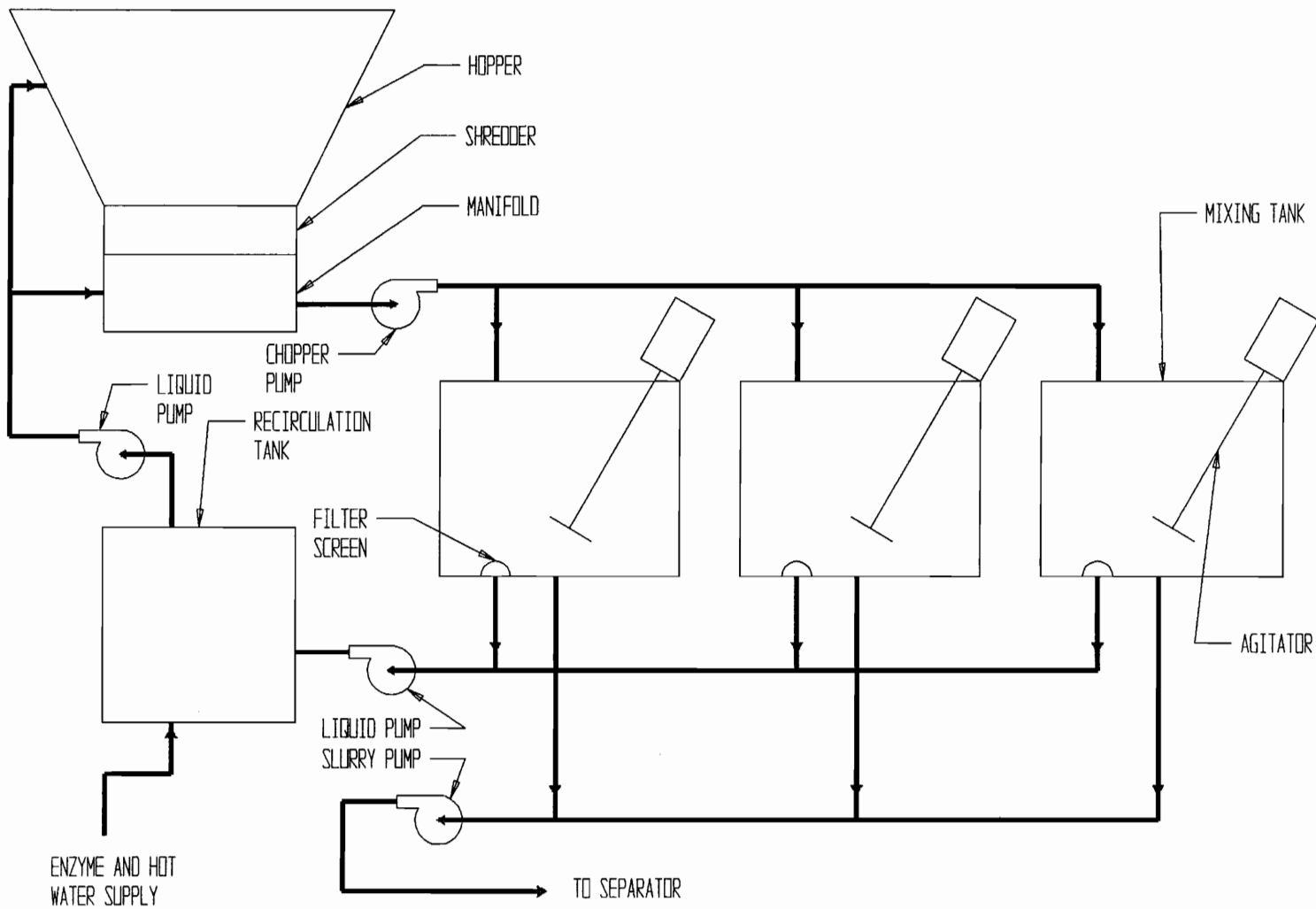
Figure 6. Dilute-Slurry Manifold System with Liquid
Recirculation and Secondary Size Reduction
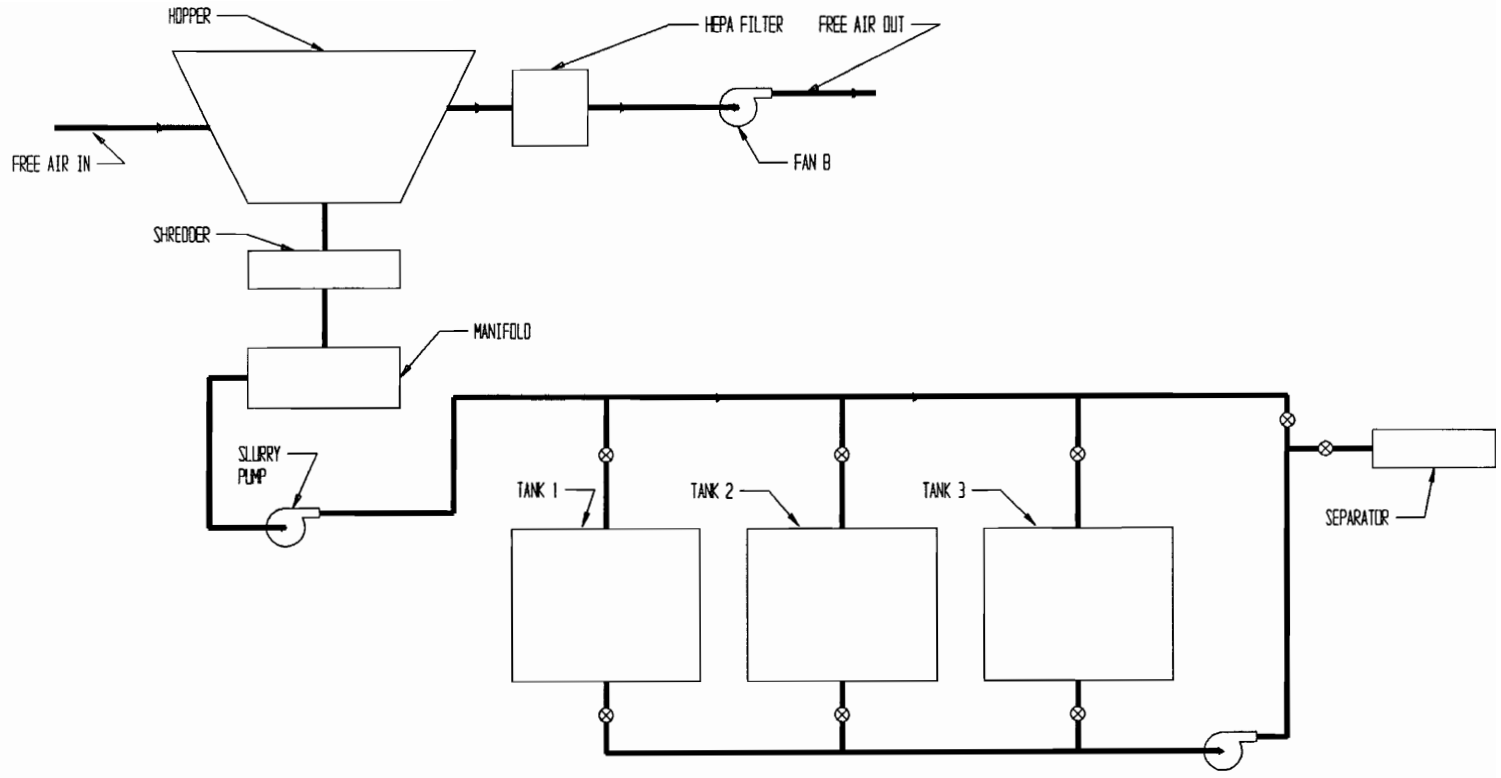
Figure 7. Thick-Slurry Batch System

3.2 Delivery

The process begins with a transfer of material from the operator to the system. A safety issue arises involving this opening to the interior. Material (large and bulky) must get in but pathogen-carrying particles (microscopic and airborne) must not escape.

Two obvious solutions to this problem exist. First, a state of negative pressure may exist within the system, with the exiting air passing through a HEPA type filter. In that case, airborne particles will not escape the constant draft that flows into the hopper. Second, a water-trap (or some equivalent) may be used to prevent the escape of gases from the interior. Such a delivery system would operate much like the trap in a sink or toilet. Due to the emphasis on cost and the large amount of liquid required, the second option has not been pursued. A state of negative pressure will exist within the system.

If we assume that the entire delivery operation must occur within the 10-foot ceiling, then it becomes a matter of lifting bags or boxes to the height of the "hatch" on the inlet hopper. Methods include:

Conveyor Belts. These are cheap, commercially available and are easy to control because they can run continuously from a single drive. They take up a large amount of floorspace depending on the height of the inlet hatch and the angle at which the material can be conveyed. The elastomer belts are difficult to clean. The Rapat Corporation manufactures small stand-alone conveyor belts that would suit this application. Other manufacturers include Buck-El. Inc. and W.A. Powers Company, Inc.

Lift Mechanisms. These include lift-and-tilt tables and mechanisms such as those found on garbage trucks for lifting and rotating dumpsters. Cart-dumpers are included in this category. They are more expensive and must be designed to operate at fairly high speeds because only a small amount of waste may be conveyed to the inlet hatch at one time. The design of such a mechanism depends to some extent on the type of cart used to transport the material throughout the hospital. ABEL Manufacturing will design and fabricate lift-and-tilt tables to specification. Stock lift mechanisms may be purchased from Vestil Manufacturing Co. and from United Tool and Stamping, Inc.

Human Power. This form of delivery is cheap (in the short term) and available, but is undesirable because of potential safety hazards to the operator. This method requires the operator to throw bags or boxes directly into the hatch, possibly after ascending a ramp. Head room is an issue, and the possibility of an operator actually reaching in through the hatch makes it unlikely that such a system would be licensed.

It has become apparent that hospitals are willing to add chutes and trapdoors in many instances to alleviate the delivery problem. Having a human operator drop the bags of waste into a waste chute from a higher floor is probably the simplest, safest and cheapest alternative. Material is simply gravity-conveyed into the top of the infeed hopper. The variability in hospital architecture makes it obvious that delivery systems for each installation will be decided on a case-by-case basis.

3.3 Size Reduction

"Size reduction" indicates the granulation of medical waste to some maximum particle size, probably about 0.5 inches. The types of size reduction devices available are many and varied. Many have been developed for specific materials, such as rock, and are not presented. Those that seem likely for this application include:

Chopper- or Grinder-pumps. These are centrifugal pumps that have an impeller capable of grinding, crushing or shearing solid particles suspended in the liquid that is drawn through the pump. The greatest advantage in using one of these devices is that the operation of size reduction may be combined with transporting the waste (in a liquid slurry) to some other station or unit operation. Unfortunately the chopper-pumps have too many disadvantages to merit further investigation for a system of this scale. They can only pump a fairly dilute slurry, bogging down if the solid mass content rises above a few percent. They are prone to a great deal of wear depending on the hardness of the solids being pumped (glass and surgical steel are a problem). Only objects below a certain initial size can be conveyed to the pump inlet. Most importantly, the amount of size reduction is somewhat random and cannot be controlled. It is believed that these pumps may be useful as slurry recirculators on systems of a much larger scale (10 or more tons per day). One reputable manufacturer of this type of pump is Vaughn Pumps, Inc.

Shredders. Batteries of slowly rotating cutter-teeth draw material in while shearing it to size. Waste can be shredded dry and size can be controlled by placing a mesh beneath the shredder outlet. Many industrial shredders are commercially available, and at least one manufacturer (Franklin Miller) markets a

device specifically for medical waste. Medical waste destruction is not a severe-duty application for these machines, so maintenance and wear are within acceptable limits. A shredder can open whole boxes or bags of waste; there is no practical size limit on the objects which may be granulated in this manner. The disadvantages include size and cost. An average industrial shredder will weigh one to two tons and will cost tens of thousands of dollars. Franklin Miller, Hi-Torque and Excaliber all manufacture industrial shredders suitable to this application.

Dispersers. High-power agitators, blenders, dispersers and other types of severe-duty chemical process equipment are available to destroy the solid waste within the reaction tanks. These devices have all the advantages of shredders but one: the particle size of destroyed waste cannot be controlled. Cost and size are comparable to those of shredders, but these pieces of equipment are considered less safe because the actual cutting blades operate at much higher speeds. Only Shar, Inc. has recommended a specific "buzz-saw" agitator for this function.

Hammermills. This technology is being employed in several chemical treatment facilities including Condor and Medical SafeTec. High-speed flails actually beat the waste to pieces. There are materials that confound this type of equipment, including most elastomers. Hospital waste must be sorted to insure that only objects that can be hammermilled pass through the system. A secondary size-reducer, called a granulator (essentially a small one-bladed shredder operating in a screen drum) can insure that particle size is within limits. Because of the need for waste separation, this method of size reduction has not been pursued.

The scale of the system being designed, as well as the available headroom, dictate the use of a shredder. Because of the high cost associated with this device, it is desirable to use it to capacity, continuously shredding material throughout the working cycle. Material to be shredded must then be held above the shredder inlet in a hopper such that gravity constantly provides material to the shredder teeth. Dimensions of the shredder will in some ways dictate what kind of a delivery system may be used. A negative pressure hopper must be attached to the hopper inlet, and a method of conveying material from beneath the shredder must be developed.

It is believed that this is the best technology available for this or larger scale systems. Only the shredder permits a completely arbitrary waste stream. Designers of much smaller systems may find that some separation of waste is acceptable and that the operating cost of reacting very low mass-concentration slurries is not all that important. In such a case, chopper pumps may be recommended.

3.4   Reaction

Waste material in its destroyed state must be mixed with liquid for the bioremediation process to occur. Vigorous agitation of the mixture must continue for one to three hours within the reaction vessels. The types of vessel available depend on the type of agitation being used.

Mixers. These include the well-known propeller mixers. Top- or side-entry, fixed or clamp-on, these mixers are the workhorses of the chemical processing industry. They are cheap and their operation is familiar. These mixers attach to ordinary reaction vessels. There is a limit to the thickness of slurry which can be effectively

agitated in this manner. Philadelphia Mixer is one of dozens of mixer manufacturers that have been contacted. Jaygo, Inc. and Warman International, Inc. have also recommended mixers to perform this task.

Blenders. Many types of slow-speed high-viscosity blenders are available for the folding of dough or gum, the processing of polymers, and the mixing of solids with liquids. Most of these devices are very specialized and tank and agitator come as a unit. Cost is high, as is energy consumption. A very thick slurry can be agitated in this manner, but it sometimes difficult to move material into or out of these agitators. Cement-mixers are a good example of this type of agitation. A ribbon blender is a more process-oriented example. Patterson Industries advertises a wide variety of this type of equipment. EMI, Inc. and Scott Equipment, Inc. also advertise specialized equipment for this purpose.

It is difficult to move a thick slurry, so it has been decided that a more dilute mixture would be processed in standard closed reaction vessels. Propeller-type mixers will be recommended for this application. It is believed that slow cement-mixer type reactors may have merit for very small-scale designs, such as for doctors' offices or small clinics.

3.5 Separation

There are numerous ways to separate solids from liquids. Many are specialized and expensive. Two general categories of separators exist. Namely, those that remove water from an absorbent material, and "dewaterers" which allow water to drip or run off of non-absorbent materials. The distinction is vague, and the applicable technology depends on the freeness of the solids and the slurry concentration of the stream to be separated.

Methods that were investigated are discussed below.

Traveling Screens. A slurry is pumped through a moving mesh which permits water to pass while restraining solids above the mesh size. The screen may travel for some distance, allowing more water to drip off. At the end of its cycle, the screen undergoes some geometric change (perhaps turning upside down) such that solid material is removed from the screen by gravity, or scraped off by a stationary blade. Mesh conveyor belts are an example of this type of separation system. It is generally applicable for the separation of relatively large particles from a dilute slurry. DonTech, Inc. custom fabricates several types of rotary-drum strainers that seem likely candidates for material dewatering. General Kinematics and Reynolds, Inc. provide several conveyor-belt type dewatering devices.

Presses. There are several mechanisms available for squeezing the water out of absorbent solids. A screw conveyor with a converging outlet efficiently compacts material, squeezing out as much as eighty percent of the entrained liquid. These "screw-presses" generally work well only if the free liquid has already been removed. Both American Screw-Press and DonTech, Inc. have systems capable of removing water from the diverse Bioconversions waste stream.

Centrifuges. Also called extractors, these devices work much like the spin cycle on a commercial washing machine. Particles to be separated must be larger than the mesh size of the spinning drum. This is the most efficient way to remove a large amount liquid from absorbent material, but it is very limited due to the particle-size restriction. Other problems include high cost and the removal of dried

solids from the centrifuge interior. No centrifuge has been found that would be suitable to the processed slurry of medical waste.

Dryers. Warm air may be directed across or through the dewatered waste stream to "blow-dry" solid particles. Alternatively, radiant heaters may vaporize the majority of the liquid trapped in the waste stream. Theoretically, both these methods can approach 100% water removal. Commercial systems assume that all the free water has been removed (perhaps on a traveling screen). The capitol investment in a system such as this is not unreasonable, but operating costs are extremely high. It is believed that this technology is not suitable for the Bioconversions application.

Other methods do exist, such as vacuum bags, flat presses and the like. These are not well-suited for removing liquid from a stream of diverse materials and widely varying sizes. The Bioconversions application requires that much of the liquid be removed from the absorbent materials, so dewatering (free liquid removal) will not be adequate. It is likely that two separate systems will be employed. The first will "drip-dry" the material, and the second will remove much of the remaining liquid from the absorbent materials.

3.6   Control

The hardware used to control this system will depend to some extent on the amount of interaction desired between the operator and the system. A series of toggle switches and analog gauges would allow the operator a great deal of control, and would make the system prone to human error. A system with little or no human interaction could be controlled by a "black-box", depending on the operator only to turn it on in the morning

and off at night. Of course, we must assume that human initiative is needed to deliver the bags of waste to the system. We must also realize that a human being will probably be necessary to oversee the operation of the system for legal reasons. As such, an attitude of one-way interaction can be adopted. The operator will be kept updated on the status of all systems and subsystems, and will be alerted in the event of any emergency or non-standard occurrence. The operator will interact with the controller only in the sense that action may be taken (through the controller) in the event of an emergency, e.g., to shut a valve if a leak is detected. The operator may also control certain pieces of equipment which are not critical to the reaction process. For instance, if the operator knows that no more waste will be delivered to the system for a few hours, the shredder may be turned off.

The quantity of information which will be conveyed to the operator requires more than simple analog output and indicator lights. A computer screen is more in keeping with this type of interface. Any type of data-display system imaginable can be configured for this application. To keep costs low, it is recommended that nothing more complex than a personal computer be used as an operator interface.

Actual control of the system is another matter. The number of motors, solenoids and relays to be actuated is quite large. More than a score of analog inputs must be constantly scanned and updated, and another score of digital (toggle) inputs must be detected. This could conceivably be done with a number of analog-to-digital boards attached to a personal computer. The overhead involved in developing such a system would be large. PLC control is the standard solution to a control problem of this complexity. Many programmable logic controllers exist and they are offered in varying sizes and capacities to meet individual needs. Once programmed, a PLC may interact with the controlled system

40

and with an output device, such as a computer screen, to display and store real-time information.

An Allen-Bradley SLC (Sequential Logic Controller) is recommended for all but the very smallest of systems. Its operation is identical to that of a PLC, but it scans inputs and controls outputs much faster. This type of controller is perfect for the process in question. It is modular, accepting extra input/output cards to allow for systems of different size and for expanding systems. It can be programmed from a PC and can interface with an operator at a number of levels, from real-time computer animation at a workstation to simple indicator lights and toggle switches. There really is no competition in this market -- the SLC undersells its nearest competitors by a large margin and has shown itself to be easily programmable.

3.7   Metering

Different enzymes, acids, bases and hot water must all be metered into the reaction tanks in precise volumes. Acid and base must be delivered in real-time to actively control the pH in the reaction tanks. It may be that the enzymes will have to be delivered separately and at different times, since they may effect one another's performance. Dry metering does not lend itself to multi-outlet applications, and it is expensive when compared with liquid metering. It has been decided that enzymes will be delivered to the installation in liquid form (probably in drums) where they will be pumped to holding tanks. Metering pumps, under SLC control, will then deliver precise quantities of liquid to a supply plenum. Metering pumps are almost always positive-displacement devices. Diaphragm and piston pumps are both in common use in laboratory and industrial applications. They may be set to a particular flow rate by hand. This flow rate may not be changed by the

controller. Investigation has shown that an inexpensive piston pump will be ideal for enzyme-metering applications. The corrosiveness of the acid and base may require a diaphragm pump. Bran and Leube, Gelber and more than a dozen other manufacturers sell reasonably priced pumps capable of doing this job.

Pumps of this type must have flooded inlets. It is therefore recommended that mobile drum pumps be used to convey liquid enzyme from the drums (in which it is delivered to the hospital) to a stationary holding tank with an attached metering pump. A level indicator must be installed to warn the controller and operator that more enzyme must be conveyed to the holding tank before the metering pump attempts to inject it into the reaction tank. It is hoped that a single low-power drum pump may be used for all the metered liquids, assuming it is flushed with clear water between uses.

3.8   Disinfection

Leaking bags and boxes will deposit potentially infectious material on every surface up to the reaction tanks. These surfaces will not be exposed to the bioremediation process. It will be necessary to disinfect the front-end of the system once a day to insure that organisms on these components cannot multiply or escape the system. This disinfection allows the HEPA filter fan to be shut down when the system is not in operation. In the tanks themselves the bioremediation process should take care of any pathogenic organisms. All surfaces past the reaction tank will see only material that has been disinfected. It will also be necessary to disinfect exposed components before any maintenance procedures can be performed on them. Available methods of disinfection are described below.

42

Misting or Fogging. Chemical disinfectants can be atomized, and the resulting mist directed onto the surface to be disinfected. Devices which perform this operation cost only a few hundred dollars and are inexpensive to operate. Disinfectant mist can be injected through a number of ports to disinfect particular subsystems or components. It has also been suggested that a large quantity of disinfectant mist (actually just a few ounces dissolved in a gallon of water) could be injected in the system at a single port and would reach every interior surface (possibly with the assistance of some air circulation). Dr. Keene of the Medical College of Virginia believes that this method would not adequately treat all infected surfaces. It is hoped that a test to be performed in the near future (refer to section 5.2) will indicate that atomized liquid does condense on all surfaces within the system. Curtis Dyna-Fog, Ltd. and Zep Mfg. Co. both sell foggers of the appropriate size for under $500.

Steam. Live steam may be injected to the system and circulated throughout. Increased surface temperature is the mechanism by which disinfection will actually occur. It is unclear how quantities of live steam will affect bearings and seals in the various process components. Furthermore, thermal expansion of shafts and gearbox components may be substantial, particularly in the size-reduction subsystem. Steam would have to be injected through a number of ports (each with a computer-controlled solenoid valve) to insure an even rise in surface temperature.

Mist disinfection is the clear winner in terms of operating cost, capitol investment and system wear and tear. The amount of disinfection actually required to meet EPA

regulations regarding hazardous environments must be ascertained before one of these systems is chosen. It should be noted, however, that an increase in the amount of disinfection can be accomplished by increasing the volume of atomized liquid injected into the system. Even if very large quantities of chemical are required to thoroughly disinfect the system, this method is recommended over steam injection.

3.9   Conveying

Material, once it is shredded, must be moved from place to place within the system. The method used depends on the consistency and phase of the material. In turn, the method of conveyance will determine what types of valves and gates may be installed in the system.

Gravity Conveying. If adequate headroom is available, one option is to let material fall from station to station, undergoing some operation in transit. The chemical disinfection system shown in Figure 1 is an example of this type of conveying. Solid pieces of waste fall into a primary grinder, then into a secondary grinder. The ground-up pieces then fall through a chemical spray and then into a screw-conveyor inlet. This conveying method is very intuitive. A system scaled to service an entire city might well have the available headroom to implement this concept.

Slurry Conveying. Solids suspended in a liquid vehicle may be pumped by several means depending on the amount, size and hardness of the solids. Centrifugal pumps such as the chopper-pumps mentioned previously can convey dilute slurries containing particles of moderate hardness and widely varying size. Large diaphragm (trash) pumps enjoy the same restrictions, but are even more

prone to wear caused by hardened particles. Several piston pumps claim to be capable of moving slurries, but macroscopic hardened particles tend to jam the pistons. Warman, Inc. makes a heavy duty slurry pump that is recommended for moving processed slurry of up to 15% mass concentration. Gelber diaphragm trash pumps are also advertised as being able to move very thick slurries. Vaughn chopper pumps are an excellent choice for more dilute slurries.

Solid Conveying. Screw conveyors and conveyor belts both transport solid material with almost no wear on the conveyor. Each must climb an incline; vertical conveyance is impossible. Therefore, each takes up a large amount of room. It is difficult to force one of these systems to serve three or more discharge points while keeping the conveyor airtight. The only types of "valves" that make sense for this application are large sliding or rotating gates which may well get jammed by stray particles of shredded waste. AFECO and the Screw-Conveyor Corporation both fabricate custom screw conveyors.

Pneumatic Conveying. Almost any material can be transported by suspending it in a stream of high velocity gas, such as atmospheric air. Materials which have been successfully transported in this manner include wet cellulose, crushed rock and live chickens. Pneumatic conveying systems are usually inexpensive, although complex feeders are sometimes necessary to introduce solid materials into the moving air-stream. A disadvantage of using pneumatic conveying is the expensive diverter valves which allow material to be deposited in separate locations. There are many types and classifications of pneumatic conveying. Proper design of such a system can offer many unexpected advantages, as will be enumerated in Chapter

4. With very dilute flows, inexpensive fluid valves may be used to replace diverter valves.

Solid conveying is being used in a number of competing systems including ABB SaniTec and the Condor systems. Because the Bioconversions system must employ multiple tanks, this is not a valid option. The difficulty and cost inherent in serving multiple discharge ports while maintaining an air-tight seal effectively rules out the use of screw- or belt-conveyors. Liquid conveying is possible, but does not offer the advantages that can be found in a properly designed pneumatic conveying system. It is likely that solid conveying systems may prove useful when developing a very large single-tank system. The bioconversions system must employ some method of slurry conveying to transport material from the reaction tanks to the separator. Slurry conveying is recommended for this operation because the material is in a dilute-slurry state at the end of the bioremediation reaction.

3.10 Valves

A great many types and sizes of valve must be used throughout the system to direct the flow of chemicals, allow the batch sequencing of reaction tanks (fill, process and dump), and to direct water and solids into separate tanks. Valves are classified by type of material in the line (slurry, liquid or vapor) and by the type of actuation. Any valve can be actuated either mechanically or pneumatically (hydraulic actuation has not been investigated). Too many valve types are available to give a condensed overview of all possibilities. The main valve applications within the system are explained, and valves suitable for these applications are suggested. All those valves recommended are on/off valves. It is believed that flow control will not be an issue in this type of design.

Slurry Valves. It may be necessary to pump a slurry of water and shredded medical waste within the system. Valves capable of this fall into two main categories: A slurry gate valve (knife-gate) is simply a liquid gate valve that is especially resistant to wear caused by particles becoming lodged in the seat. A pinch valve, on the other hand, actually squeezes shut an elastomer section of piping, sealing around any solids that may be in the way. Pinch valves have been successfully sealed around tree branches and pieces of shale. The amount of wear and severity of potential leaking problems will dictate which valve to use. It is suggested that knife gates be used only when the potential for particles becoming lodged in the seat is small. Washing the slurry through the pipe with a charge of clear water before closing is a good way to prevent the valve from becoming jammed. Pinch valves almost never become jammed, but tend to leak slightly. Valves used for this application are usually placed of large lines. It is therefore customary to actuate them pneumatically when they must be computer-controlled.

Small Liquid Valves. Small quantities of liquid, such as metered chemicals, are often controlled with solenoid-actuated globe valves. The wear-resistance of globe valves makes them an excellent choice for many on-off applications. Solenoid actuation offers the further advantage of choosing the mode of failure during a power loss (fail-closed or fail-open). Poppet- or spool-valves may also be used for this application, but are more prone to wear.

Large Liquid Valves. Liquid valves on large lines should be actuated pneumatically. An air-cylinder actuator on a butterfly or ball valve is a good choice. Pilot-valve actuation may be used only if the fluid is very clean.

Steam Valves. Ball valves may be use in low-pressure steam lines, but globe and gate valves are the traditional choices because of their excellent wear characteristics. Steam lines will be quite small if needed at all, so solenoid actuation is recommended.

Pneumatic valves can be configured to fail open, fail closed or fail last (remain in current state when power or air pressure is lost). Compressed air is available at most hospitals. Where sufficient quantities of compressed air are not available, a separate compressor of the size needed is not expensive. A solenoid valve is needed to open the air-supply line to any pneumatically controlled valve or pilot valve. It is recommended that motor-actuation be avoided due to cost.

It would be pointless to recommend one brand of valve over another. It is recommended that a local distributor (such as Virginia Valve Company in Roanoke, Va.) be contacted and that his brand recommendations be followed.

TABLE 3. Component Selection for Serial/Parallel Processing

DELIVERY	SIZE REDUCTION	CONVEYING	REACTION	SEPARATION	DISINFECTION
Conveyor Belt	Chopper- or Grinder-Pump	Solid/Dry	Mixer	Traveling Screen	Steam
Lift Mechanism	Shredder	Liquid/ Hydraulic Slurry	Blender or Disperser	Press	Aerosol Chemical Disinfectant
Gravity	Disperser	Air/Pneumatic		Centrifuge	Liquid Chemical Disinfectant
Human Power	Hammermill			Dryer	

CHAPTER 4
THE FINAL DESIGN

4.1 Overview

The design of a system specifically developed to meet all the restrictions in Chapter 2 will now be presented. A good deal of variability has been left in the actual process parameters because the actual bioremediation process is not yet fully defined. The system presented should be adaptable to any reasonable set of reaction parameters specified by the biochemists developing the process and by the Commonwealth of Virginia.

The overall system consists of subsystems and peripheral systems as specified in Chapter 3. Medical waste is delivered to a shredder, then pneumatically conveyed to reaction tanks where it undergoes the bioremediation reaction. The processed slurry is then pumped to a separator which delivers mostly dry material to a collection bin or dumpster. Individual components and control schemes will be discussed.

4.2 Delivery System

The delivery system was initially envisioned as a small conveyor belt. Although inexpensive, the conveyor belt takes up a great deal of floor space, runs continuously, allows a permanent opening from the shredder to the outside environment and is difficult to clean and disinfect. Its one big advantage is that it can easily meet the ten-foot ceiling restriction. A conveyor belt *must* be used wherever the height restriction is strictly enforced. A cart-dumper or lift-mechanism may be used where headroom is available but gravity delivery is impractical.

Preliminary meetings with the administration of our prototype installation facility, Lewis-Gale Hospital, indicate that they are willing to allow an installation with as much as twenty feet of headroom. A gravity fed delivery system, such as a chute or trapdoor is the best option where available. The increased headroom allows a greater storage volume over the shredder and it eliminates any moving parts from the system front-end. The proposed installation site is adjacent to the current medical waste storage room and fourteen feet lower. It will be a simple matter to modify the wall slightly to accept a trapdoor and chute similar to the one currently serving their on-site incinerator.

The chute will empty waste directly into the shredder infeed hopper, which will be fabricated of stainless steel sheet with dimensions suitable to the installation site. The operator will feed bags/boxes of waste through the chute into the hopper in quantities sufficient to occupy the shredder for continuous running. Should the operator be unable to supply more waste to the hopper, the shredder may be shut down as a controller option.

A blower capable of inducing a 5 ft/second draft through the chute will pull air through a HEPA filter and exhaust to the atmosphere, causing a state of negative pressure within the hopper. Should this blower fail, the operator will be notified to close the chute hatch immediately. A source of makeup air must be available to the fan when the hatch is not open. It is suggested that a dust-tight (but not air-tight) top to the hopper will provide enough openings for the blower to function. Alternatively, the blower may be interlocked to an air-tight chute hatch so that it only runs when the operator has the hatch open. This will significantly prolong HEPA filter life.

4.3 Size Reduction System

At the bottom of the hopper is the inlet to a Franklin Miller Taskmaster Shredder. This line of shredders is shown in Figure 17. Material is shredded until it is small enough to pass through a metal screen of 0.5 inch mesh. Two motors (25 HP and 15 HP motors running in parallel) drive the shredder, auto-reversing in the event of a jam. A size reduction mesh (also provided by Franklin Miller) attaches to the shredder discharge. Any material not small enough to pass through this grate is recirculated to the inlet, where it is re-shredded until it is fine enough to pass through the openings. Changes in cutter thickness and mesh size (among other things) affect the absolute shredder throughput.

The shredder specified for this system is a Franklin Miller 2330 Taskmaster. It will be ordered with the following attributes:

- Carbon steel construction
- 23" x 30" cutting chamber
- Heavy Duty 24" stand with castors and jack-screws
- Sizing Screen
- 25 HP and 15 HP 480 volt/3 phase motors (operating in parallel)
- Shaft speeds 30/15 RPM
- Motors to be mounted underneath shredder
- Special type 27 (labyrinth) face seal
- Overload Sensing Controller in NEMA 12 enclosure
- Start/stop push-button, reset button and starter
- Hand off/auto switch

In terms of throughput and uniformity of throughput, a shredder is the best option for size reduction. Chopper and grinder pumps allow a wide distribution of particle size, and can get bogged down easily. Further, other size reduction schemes suffer from excessive wear if metal is present in the waste stream. The particular shredder chosen was selected on the basis of cost and the exceptional seal cartridges that make it less vulnerable to steam,

moisture and stray particles in the gearbox. The shredding chamber is 23 inches deep, placing the shredder inlet about four feet off the floor. Any headroom above that is available for the waste hopper. Delivered material must be raised to a height of at least six feet so that a two-foot long box may be expected to fall onto the shredder blades.

4.4   Solids Conveying System

It is believed that a slurry mass concentration of more than 5-6% will be impossible to pump by conventional means. This is substantially lower than the concentration at which material can be processed in reaction tanks. In some cases much denser slurries can be pumped without difficulty using inexpensive chemical processing equipment. The apparent reason for the unexpectedly high viscosity in this particular mixture is twofold. First, a large percentage of the waste stream is absorbent. Liquid that is absorbed by the shredded paper or textiles is not available as a vehicle in which solids can be transported. Second, fibrous materials in close proximity tend to bind to one another, much like reinforcing fibers in high-tensile concrete. Both these factors depend largely on the high content of undigested paper in the slurry. Although slurries of up to 35% solid content can be transported with centrifugal pumps, those solids are always of a dense, non-absorbent material such as sand or plastic beads.

Rather than invest in more tanks to process the same amount of waste, pneumatic conveying has been chosen to move the just-shredded waste into the reaction tanks. This has proved to be an excellent solution. Aside from solving the pumping problem, the pneumatic conveying system offers the following benefits:

1) Proper placement of the blower and diverter valves allows all tanks, piping and ductwork to exist in a state of negative pressure whenever the pneumatic conveying system is active; that is, whenever the system is in use (see Figure 8).

2) A large percentage of the piping carries no liquid. A leak, or a failure necessitating cleanout, is not the messy job it would be with slurry conveying. A very lean-phase mass ratio insures that the pipes leading from shredder to reaction tank will have relatively little contaminated material (all reasonably dry) in them at any one time.

3) The number of valves necessary for the entire system is reduced dramatically. The valving system necessary for slurry conveying had a cost of nearly $30,000. The diverter valves necessary for the pneumatic conveying system cost $2000 - $3000 each, but only two of them are necessary. It may be that using 4 ordinary gate valves would be equally effective and not nearly as expensive. This merits investigation once an initial prototype has been developed.

4) Solid-air separation is very easy to accomplish. Therefore, very low solids concentrations may be conveyed and the air recirculated. Conversely, separating solids from a low-concentration solid-liquid slurry is a very difficult problem.

One of the main elements to pneumatic conveying is the separation of solids from the air stream once the destination has been reached. The relatively large particles which are being conveyed suggest inertial or "cyclone" separation. It was suggested that the curvature of the reaction tanks might be sufficient to spin the solids out of the air stream.
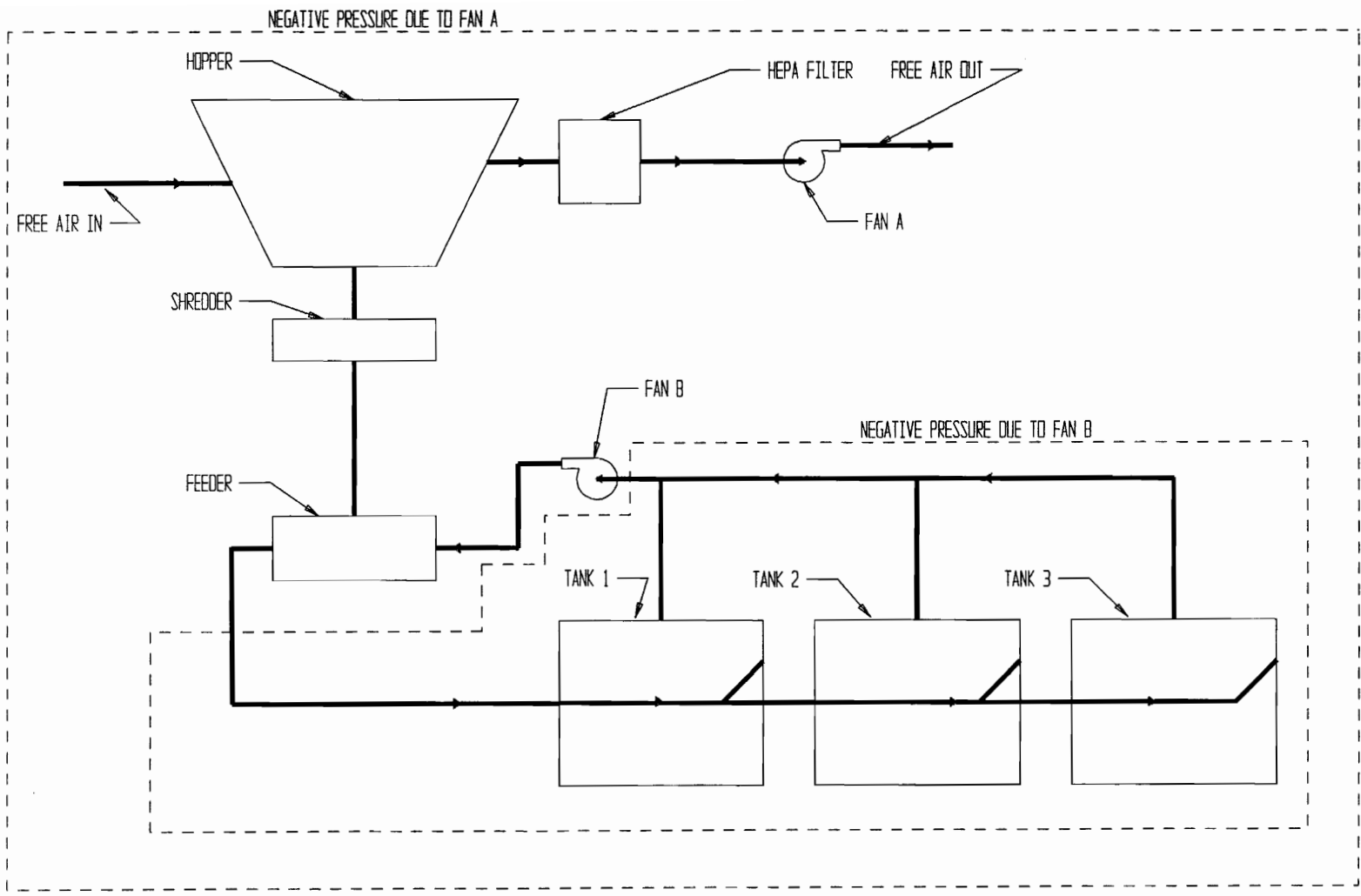
Figure 8. Pneumatic Conveying System

This has been shown to be the case, as is explained in Chapter 5.

Once processed, material is pumped to a solid-liquid separator, described below. The slurry pump chosen for this task is a Warman Hurricane with the following attributes:

- Model 3/2 CAC CCCM
- Hi-chrome casing and Hi-chrome impeller (recessed)
- Durametallic double CRO mechanical seal
- 3 HP 1800 RPM drive (3/60/230-460)
- V-belt drive (adjustable)
- Operating point = 865 RPM / 100 GPM / 25 feet head
- 3 inch suction flange
- 2 inch discharge flange

It is fair to ask why, if the material can be pumped, it was necessary to use pneumatic conveying to move the solids into reaction tanks in the first place. The answer is that the bioremediation reaction drastically alters the consistency of the slurry. Most fibrous materials (paper and cloth) are digested by an enzyme that attacks cellulose. Much of the absorbent material is liquefied. Apparent viscosity then drops to the point that the slurry may be pumped out of the reaction tanks.

4.5   Reaction and Agitation

The same characteristics that make an undigested slurry difficult to pump make it difficult to agitate. A test performed by Philadelphia Mixer, Inc. indicated that the material we were proposing to mix could be agitated at a mass concentration of no more than 9%.

The test did not take into account the fact that fibrous material would begin hydrolyzing as soon as it entered the tank. The actual amount of solids that could be added to a tank depends on the rate at which solids are added to a bath of initially pure liquid, and the rate at which a particle of paper hydrolyzes once it has been conveyed to the tank. Both these

quantities are unknown and difficult to test without full scale processing equipment. This compounds the problem that the waste stream is not perfectly uniform; the percentage of fibrous materials in each batch may vary.

Rather than develop a model taking all these unknowns into account, the process will employ a dynamic control system to determine when enough material has been added to a reaction tank. It is based on the following assumptions:

1) Motor current draw varies in a well-behaved manner with respect to viscosity and agitatibility.

2) Viscosity and motor current draw will decrease with respect to time for a given batch with a fixed quantity of solid waste. This is due to the digestion of the solids already in the bath.

3) The rate at which current drops is indicative of the absolute amount of solids in the tank. A point will be approached at which the current will drop only slightly even if no solid material is added for a considerable length of time. A quantity indicating the ability of the tank to accept more waste can then be calculated to determine whether the diverter valve should be open or closed.

Based on these assumptions a control scheme can be developed to allow the system to efficiently deal with waste streams of any reasonable consistency. The mass and enzyme concentrations necessary for effective treatment will also be taken into consideration. The high torque rating of the motor will not be wasted. Every tank will run as full a load as

possible. The mixer, provided by Philadelphia Mixer Co. will be as follows:

- Top-entering MT-02-PTS
- 5 HP 1750 RPM motor (3/60/230-460)
- 2 inch diameter agitator shaft 54 inches long
- Two impellers (22 inch diameter) operating at 125 RPM output speed
- 6 inch 150# flange
- High pressure stuffing box
- Wetted parts of 316 ss

The tank is to be ordered concurrently with the mixers and will be purchased from Precision Equipment Co. as follows:

- Indian Tuff-Tank
- 304 ss with 2B finish
- 5 foot diameter x 4.5 foot straight side
- Flat top, dish bottom
- Fittings to be specified

The reaction tank will need to be insulated to prevent excessive energy loss from the hot slurry. Preliminary calculations indicate that two inches of fiberglass insulation will prevent a temperature drop of more than 3 degrees Celsius over the course of two hours. External pad-type electric tank heaters will be installed to counter this small loss, if necessary. The heaters will also be needed to keep the reacting slurry at temperature should an agitator fail.

4.6   Separation

A trip to the manufacturing facility of DonTech. Inc. in Chicago, Illinois revealed that their recommended screw-press separator was designed to accept material that was already drip-dried, i.e., had the free water removed. A somewhat smaller two-stage system proved to be more in line with our needs. The first stage, a rotary screen, removes most of the free liquid. Solids caught on this drum are continuously scraped off by a stationary nylon blade. Wet (but not dripping) material then falls into a smaller screw conveyor

where still more water is squeezed out, and the volume of the dried material is considerably reduced.

DonTech, Inc. will manufacture the two-stage "Roto-Press" system capable of removing particles down to 0.005" in diameter. The screen mesh can be specified to allow a coarser separation, thereby increasing the possible flow rate through the separator. Figure 9 is a drawing of one of the roto-press devices. A 5 HP drive has been suggested for our application. The separator may be placed at a substantial distance from the actual system (depending only on the capabilities of the slurry pump) and may be elevated so that dried material will fall into a bin or dumpster.

4.7   Disinfection

It will sometimes be necessary to disinfect the system to allow safe disassembly or standard maintenance. It may also be necessary to disinfect the front-end (hopper and shredder) once a day to meet state or federal regulations regarding safety in the workplace. This will be accomplished by fogging the interior of the hopper and manifold assembly (including the shredding components) with a high concentration of tuberculocidal disinfectant. Though not theoretically necessary, the disinfectant mist can travel through the piping to coat the interior of tanks, valves and pumps. Should small doses of the disinfectant prove to be an irritant, the operator may wish to begin the disinfection cycle at the end of each work day, then close the room and leave. The mist-disinfection can be SLC controlled.

Misting has been suggested to the project personnel by companies that sell the mister or the disinfectant. Although the cost (startup and operational) is remarkably low, there is

ROTATING DRUM
FILTER

FILTER
SCRAPER

RAMP TO
CONVEYOR
TROUGH

SIZE REDUCTION
CONE

60

TO DUMPSTER

AUGER

WATER FILTER

SPRAY NOZZLES

TO SEWER
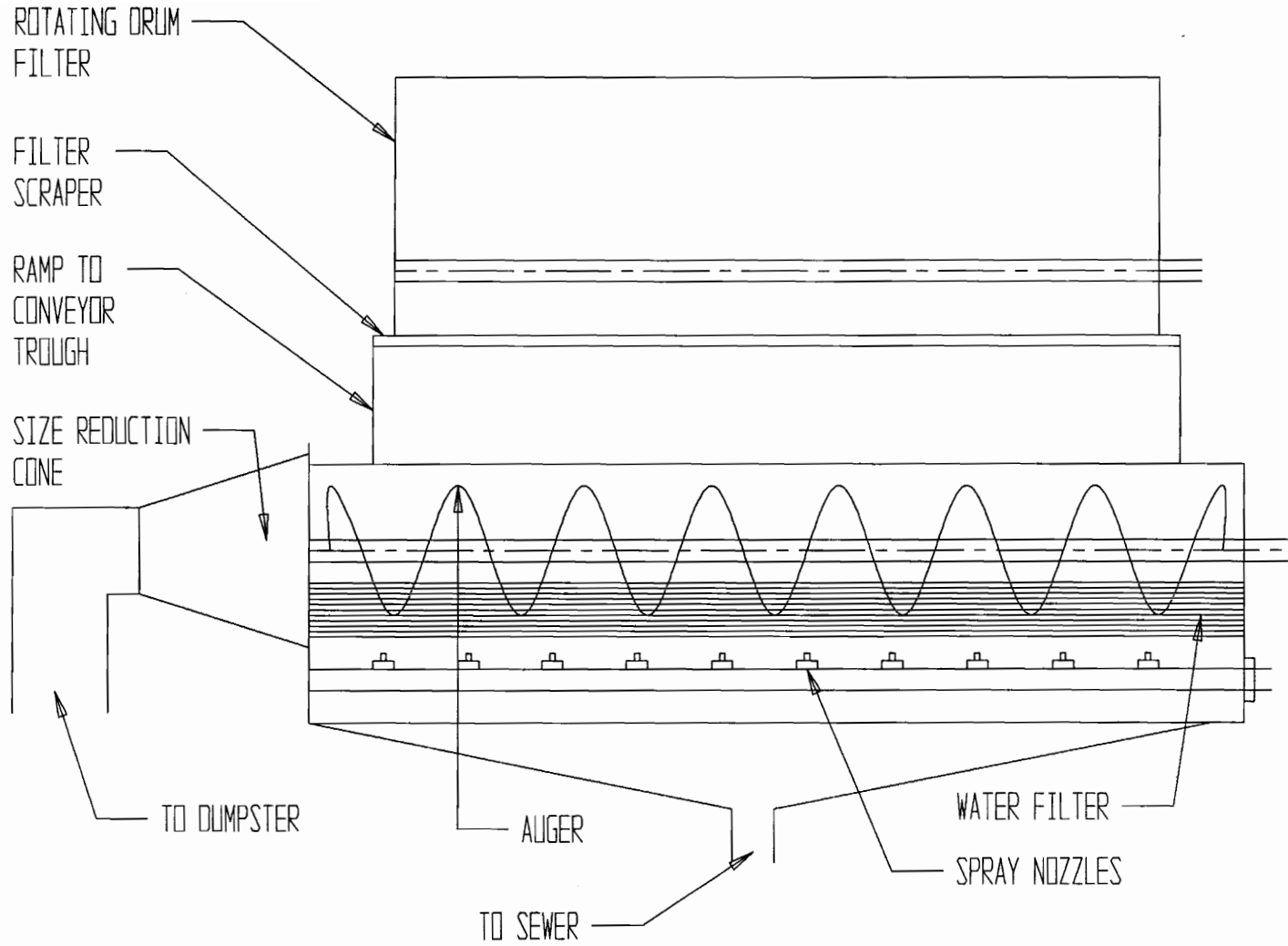
Figure 9. Don-Tech Roto-Press Device

some question as to whether enough disinfectant will reach every surface. Misting systems have recently fallen into disrepute with experts in sterile systems (Dr. Keene of M.C.V.) Live steam injection has been recommended as an alternative. It should be pointed out that the interior of a waste disposal unit is not a traditionally sterile environment. It is believed that mist disinfection is sufficient for this type of application.

4.8 Valves and Piping

All valves in the system will be pneumatically actuated except for small solenoid line valves. Because a pneumatically actuated valve must have a solenoid valve on the air supply line, it will seem to the controller as though all the valves are solenoid actuated with exactly the same signal. A valve air supply scheme has been recommended by Piedmont Hub, Inc. to force all pneumatically actuated valves to fail open, closed or last at our specification. Fail last means that the valve will remain in whatever state it was at when loss of power occurred.

All valves controlling the delivery of chemicals (not water) to the reaction tanks will be solenoid-actuated globe valves installed in stainless steel lines of standard 1/4 inch tubing. These valves shall be of the fail-closed variety. Valves on the reaction tank discharge flanges shall be air-cylinder actuated knife-gates for slurry service. Other actuated valves on the slurry line shall be air-actuated pinch-valves. Air-actuated butterfly valves shall be placed on the main water delivery lines. These shall all be of the fail-closed variety.

Valves on the pneumatic conveying (dry slurry) lines cannot yet be specified. Testing described in Chapter 5 will indicate whether gate, pinch or diverter valves can be used. Long-sweep elbows are to be used wherever right-angle turns are necessary. Whenever

possible, 45 degree turns are preferable to elbows. Thus, when raising the level of a pipe by 10 feet, it is preferable to install a 14 foot section of pipe at an incline rather than a 10 foot vertical section to span the difference in height. This unorthodox geometry will lower the head loss around bends by reducing the momentum change of the solid particles.

Solenoid plug- or poppet-valves on the compressed-air supply lines must be of the fail-open type so that in the event of a power failure, air pressure will be delivered to the valve actuators, thereby closing them. Valve seats and packing for the liquid or slurry lines shall be chosen to withstand the pH range present in the tank.

All pipes and fittings are to be of stainless steel. Mechanical joints shall be used wherever possible to facilitate disassembly during maintenance. Stainless steel tubing and tube fittings shall be used to convey all chemicals.

4.9 Control Scheme

4.9.1 Controller Hardware and Software

Different options are available (hardware and software) for the Allen-Bradley SLC described in Section 3.6. It is recommended that an SLC500 be used for this system. It shall be programmed using ladder-logic programming software (distributed by Allen-Bradley) and interfaced to the operator through the GENESIS package (Iconics, Ltd.) on a personal computer. Touch screens are deemed unnecessarily expensive for this application, and the option of installing a BASIC module to interface with the SLC is seen as insufficient in terms of savings versus user friendliness.

4.9.2   Process Programming and Controller Strategy

Perhaps the most important element of this design is the control strategy. Originally, a primary process assumption was that a certain mass of material constitutes a batch and that this mass is determined by how long the shredder has been running. This has been changed to allow more variability in the waste stream and to allow full tank agitation as mentioned in Section 4.5. The new definition of a batch is the amount of material that can be effectively agitated. A measure of the difficulty of agitation determines when material is no longer added to the "batch."

Actually, until a tank registers "full" the process seems continuous, not a batch process at all. Both the shredder and the pneumatic conveying system run continuously, conveying the shredded material to whichever reaction tank has room (and has not entered "batch" mode). When the controller determines that a reaction tank can not effectively accept more shredded waste, the tank is said to have entered "batch" mode, and from here the process becomes a true batch process, with a timer determining when the batch is to be pumped to the separator and the tank refilled with water.

Ladder-logic is a term describing an execution environment in which the controller sequentially executes a long series (ladder) of conditional statements. This programming strategy evolved from the "ladder-diagrams" that were used to program control systems consisting only of relays and analog circuit elements. This calls for a somewhat different programming structure than that with which most digital programmers are familiar. To begin thinking about control within a ladder-logic framework, one must consider that the entire program (ladder) is executed approximately every 0.02 seconds. There is really no need to execute a sub-loop within the program for anything but the most demanding PID

(proportional/integral/differential) control. The internal registers of the SLC indicate the status of every instrument or controlled circuit connected to the SLC. A number of user-registers arbitrarily defined by the programmer allow the programmer to think logically about groups of control items. A simplistic control scheme has been developed based on these principles. The flow chart (Figure 10) demonstrates how a string of independent conditional statements can effectively control the entire system. This should provide the basis for the final ICOM control program once the hardware and software have been purchased. Of course, this diagram is not complete. It is the framework on which a complete program which takes all possible occurrences into account can be developed.

This method of visualizing ladder-logic was developed by the author to ease a new programmer into a non-classical mode of linear programming. It may be that there is an even more modular approach to this type of software development.

The flowchart depends on the user to define three user-registers indicating tank status: TS1, TS2 and TS3 (or more if more tanks are required).

These may each take on one of 5 values:

TS=0 Indicates that the tank is empty.
TS=1 Tank is being filled with liquid. Therefore no other tank is being filled with liquid.
TS=2 Tank is full of chemicals and ready to accept solid waste.
TS=3 Tank is being filled with solids. Therefore no other tank is being filled with solids.
TS=4 Tank is full of solids and is reacting.
TS=5 Tank is being emptied. Therefore no other tank is being emptied to separator.

By sequentially checking each tank-status register for each of these possible values, it is possible to determine (from instrument readings) the proper course of action. When certain conditions apply, relays are triggered and tank status is changed from within the program.
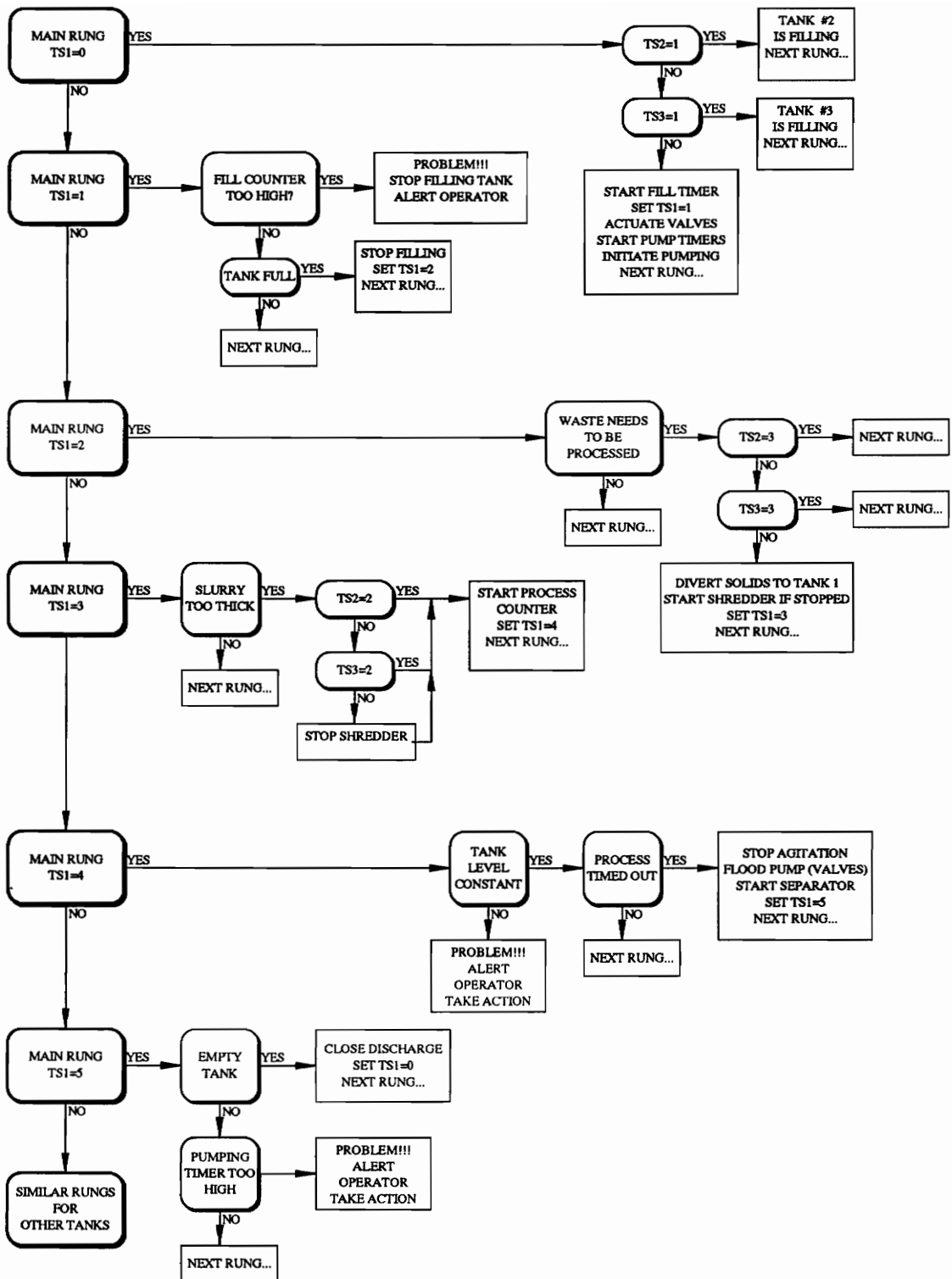
Figure 10. Control Framework for
Ladder-Logic Programming

4.9.3   Emergency and Maintenance Procedures

Any and every problem detectable by the controller must be mapped to a course of action that will insure operator safety. From a mechanical standpoint, procedures for handling a breakdown are fairly straightforward.   Reasonable precautions have been taken to minimize the amount of potentially contaminated material that could escape. Any waste, liquid or solid, must be treated as potentially infectious and reprocessed or disinfected. Hospital procedures exist for disinfecting a surface that may have been exposed to pathogenic materials. Global stops will be spaced around the system work area so that an operator may arbitrarily cut power to all components except the controller and instrumentation.

Failure of any component can be dealt with by removal, replacement, or disinfection. Only immediate mechanical (not motor related) failure of the shredder has been viewed as a potential stumbling block, and this is considered extremely unlikely. That is because shredding of medical waste is a light-duty application for an industrial shredder. Regular preventative maintenance (consisting of a yearly change of bearing/seal cartridges) should eliminate any possibility of failure of the actual shredder components. Differentiation between immediate and impending failure has been made in the procedures listed below. An impending failure is one in which some warning is given; i.e., bearing noise or a leaky pump seal. Impending failure is always detected by the operator. The controller must be alerted of the condition before it can take action. Immediate failure is one in which the component suddenly stops working, or where the component must be immediately shut down for safety reasons. Failures are described below.

Problem: Impending failure of shredder
Finish processing material in the hopper, then begin tank reaction. Disinfect front end and repair or replace failing shredder components.

Problem: Immediate failure of shredder
Operator must wear proper protection for handling of infectious waste. Allow pneumatic conveying system to run for a few minutes to clear the feeder. Disinfect system front-end as at the end of a work day. Remove any unopened bags or boxes from hopper by hand. Remove shredded material from shredder by hand or with wet-dry vacuum cleaner. Disinfect system front-end again. Repair shredder.

Problem: Immediate failure of fan or filter
Finish shredding material in hopper. Do not open hatch to hopper. Disinfect front end, then effect repairs.

Problem: Impending failure of fan or filter
Finish shredding material in hopper. Do not open hatch to hopper. Disinfect front end, then effect repairs.

Problem: Failure of pneumatic conveying line or valves
Stop shredder. Stop pneumatic conveying blower. Remove dry shredded medical waste by hand (wear proper protective garments). Close all valves and replace or repair piping.

Problem: Failure of tank agitator
Allow the bioremediation process to take place without agitation. This will take a long time. Flush tank as usual and disinfect tank interior. Effect repairs.

Problem: Failure of vessel or low-end piping
Same as for tank agitator failure.

Problem: Failure of control
Global stop. System engineers will finish batch processing control manually, then effect control repair or reprogramming.

Problem: Component failure past the reaction tanks
Stop material processing. Allow material to remain in reaction tanks until repairs have been effected. Note that the material in the tank will have been disinfected, and should therefore not be subject to medical waste storage laws.

Problem: Failure of metering system
Stop processing and effect repairs.

Problem: Failure of disinfection system
This is a hand-held component and is inexpensive. A spare fogger unit can be stored near the system.

Note that in the event of certain component failures, hitting a global stop is not the safest course of action. A hardware stop will not close all valves. The best thing to do in most cases is alert the controller to component failure, allow the controller to respond and then wait for instructions. It is important to note that the controller cannot detect all possible failures. It can, however, *respond* to all possible failures if the operator tells the controller what is happening. It will be necessary to program the SLC with an emergency interrupt which accepts input from the operator regarding system status.

4.10 Summary

To recapitulate, let us take a Laplacian approach, tracking a single particle of waste through the entire process. Figure 11 is a diagrammatic layout of the paths and stations a particle will traverse. Figure 12 is a likely configuration of the system with all components shown to scale.

The particle begins its journey as a part of a collection of medical waste (a syringe or some such) in an ordinary hospital redbag. This bag is delivered (via gravity or some lifting system that is appropriate for the installation) into a steel container above the hopper. Air is being drawn out of this container through a HEPA filter. The bag, under the influence of gravity, comes in contact with the shredder blades, therein spilling its contents about the cutters. The component containing the particle is sheared down to a size such that it can pass through a 0.5" x 0.5" sizing screen. It then falls into a "funnel" shaped steel container that directs it towards the pneumatic feeder inlet (under the influence of gravity and of air flow). The particle is quickly accelerated to approximately 30 m/s, making the
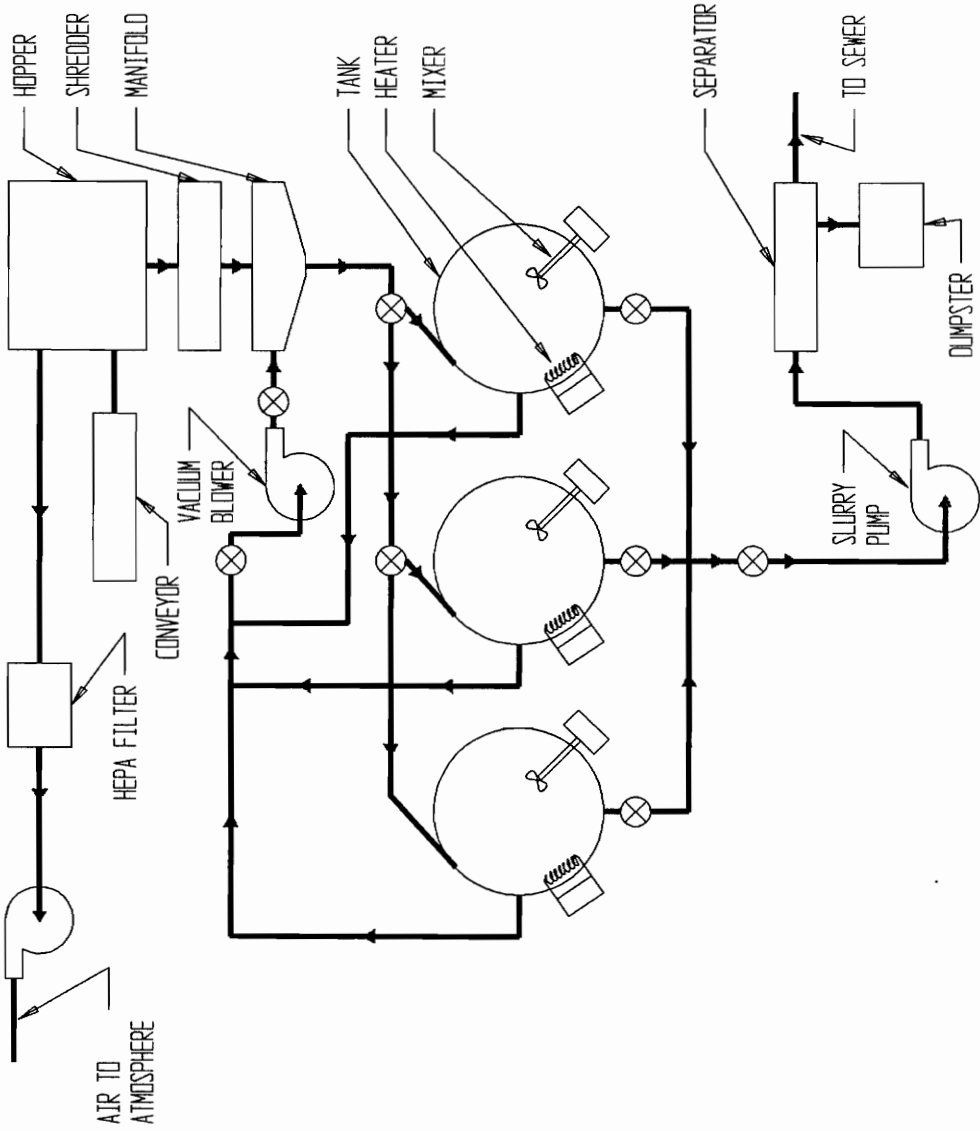
Figure 11. Bioremediation System

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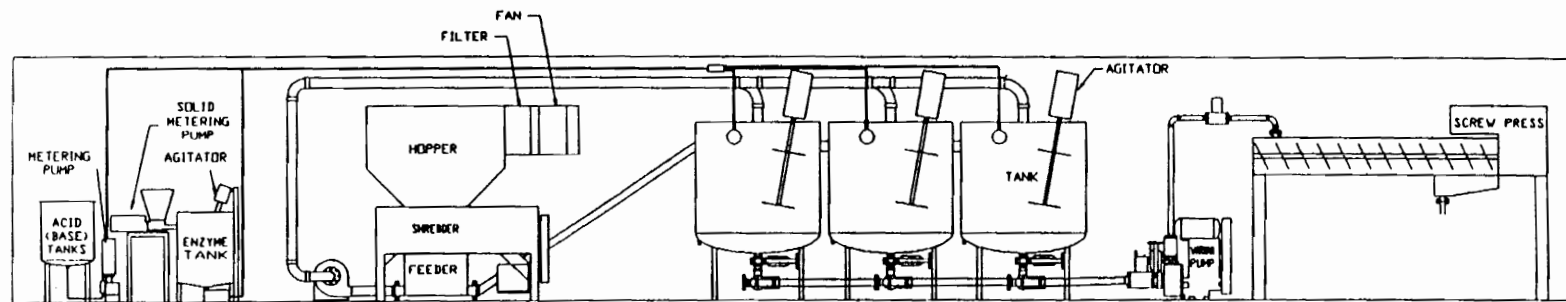
Figure 12. Serially Connected Component Layout

entire trip to the reaction tank in under a second. It may collide with a neighbor particle once or twice during the journey; the number of particles in the piping at any one time is actually fairly small. The particle enters the tank tangentially and at high velocities, experiencing an apparent 1.5 g acceleration towards the wall. This "cyclone" separation is sufficient to keep the particle and its neighbors well away from the center of the tank where air is suctioned back towards the feeder inlet. The particle will soon come in contact with enzyme solution, slowing and becoming entrapped in a slurry. When the slurry is sufficiently "thick" no more particles will be delivered to the tank. The agitation will then continue for a predetermined length of time during which the particle will experience continual interaction with its neighbors. Organisms on its surface will be attacked and inactivated by the enzymes in the slurry. These enzymes will be passed from particle to particle due to the agitation. Depending on its composition, the particle may be chemically altered (hydrolyzed). After about two hours a reduction of microbial activity of six orders of magnitude will be achieved. The process timer will run out and a valve will open, flooding the inlet to a slurry pump under the tank. The slurry in which the particle is entrained will be pumped through a rotary screen, where most of the free liquid will be removed. The solids will fall to a screw-press conveyor that will remove up to 80% of the remaining liquid. The particle, now part of a compacted paste of disinfected material, will fall into a garbage collection container and will then be transported to a sanitary landfill.

4.11 Unspecified Design Details

Some elements of this design cannot be fully specified until process constants have been further investigated. Experimentation being done by various medical and biological personnel will soon yield a time interval during which the waste must be exposed to

particular physical conditions. This number, in turn, will allow us to specify the number of reaction tanks that make the system run most efficiently. Figures 13 and 14 demonstrate the system dependence on shredder throughput and reaction time. The amount of waste that can be processed at one time depends heavily on the extent to which this concentration effects the efficiency of the biochemical disinfection. This cannot be determined accurately until a batch of inoculated waste has actually been processed in this manner. The biochemical investigators believe that a second reaction at a different set of physical conditions may need to follow the first. Variability must be left in the control scheme and various sub-systems to allow for that eventuality.

The fan and pipe characteristics needed to efficiently move the material from beneath the shredder to the tanks have been determined from empirical data collected with a small-scale model (Chapter 5). Because of the many interactions that determine the behavior of a multi-phase flow of varying composition, scaling laws cannot be perfectly applied. A full scale prototype will allow better sizing of the fan, piping and feeder inlet based on a representative load of just-shredded medical waste.

As will be mentioned in the Chapter 5, much of the current design is based on figures (throughput, pressure, mass concentrations) of which vendors claim their equipment is capable. It is possible that some components may not be sufficient for the task for which they have been specified. It may be that no reasonable component can do the job. Some design modification will then be needed.

SHREDDER

TANK 1

TANK 2

· TANK 3

SEPARATOR

FILL INTERVAL = 27 min   SEPARATION INTERVAL = 10 min
·REACTION INTERVAL = 60 min   TOTAL CAPACITY = 5940 lb/hr

SHREDDER

TANK 1

TANK 2

TANK 3

SEPARATOR

FILL INTERVAL = 27 min   SEPARATION INTERVAL = 10 min
REACTION INTERVAL = 120 min   TOTAL CAPACITY = 4455 lb/day

8:30   9:30   10:30   11:30   12:30   1:30   2:30   3:30   4:30
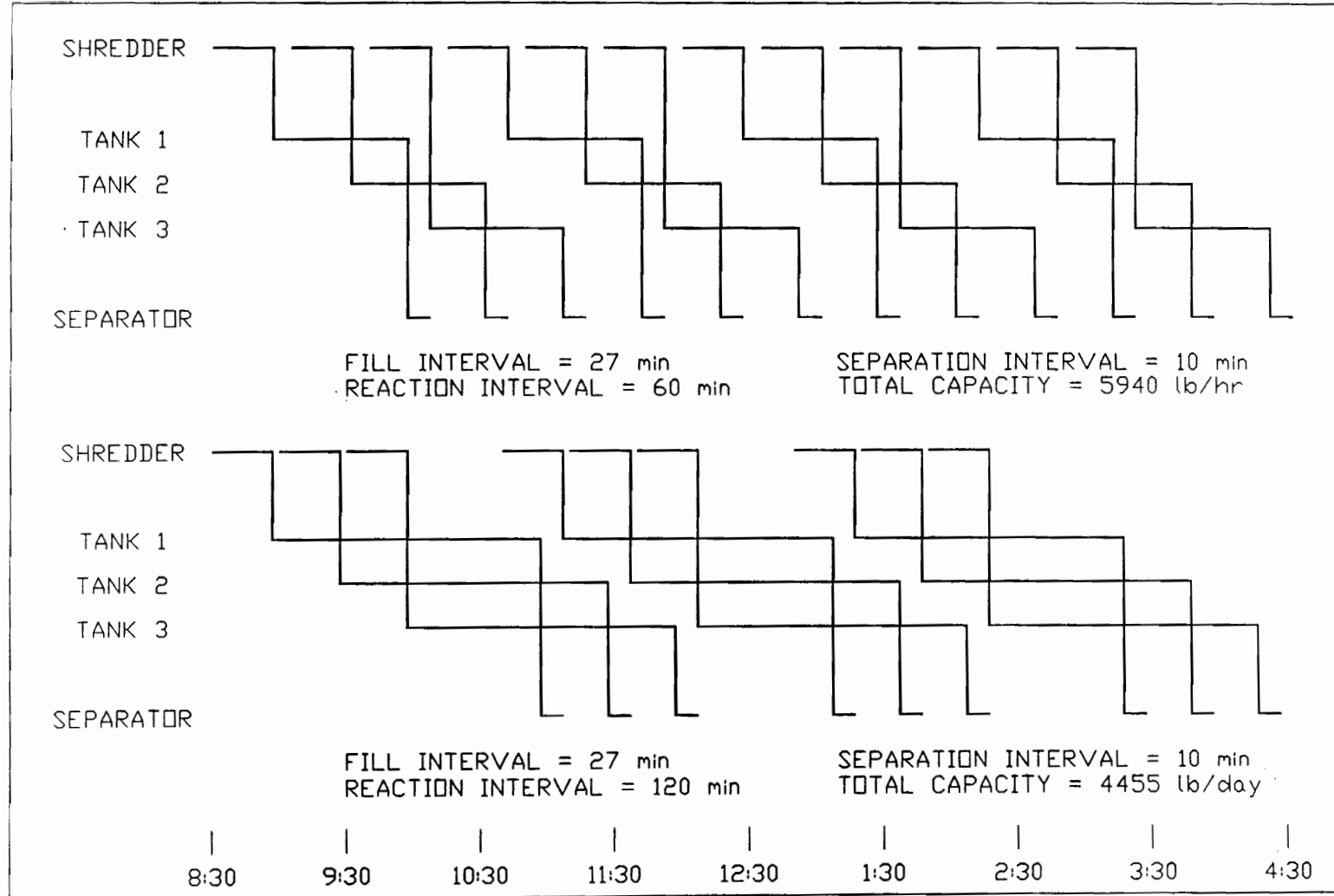
Figure 13. Process Diagram with 800 lb/hr Shredder Throughput

FILL INTERVAL = 37 min   SEPARATION INTERVAL = 10 min
REACTION INTERVAL = 60 min   TOTAL CAPACITY = 4950 lb/day

FILL INTERVAL = 37 min   SEPARATION INTERVAL = 10 min
REACTION INTERVAL = 120 min   TOTAL CAPACITY = 3960 lb/day
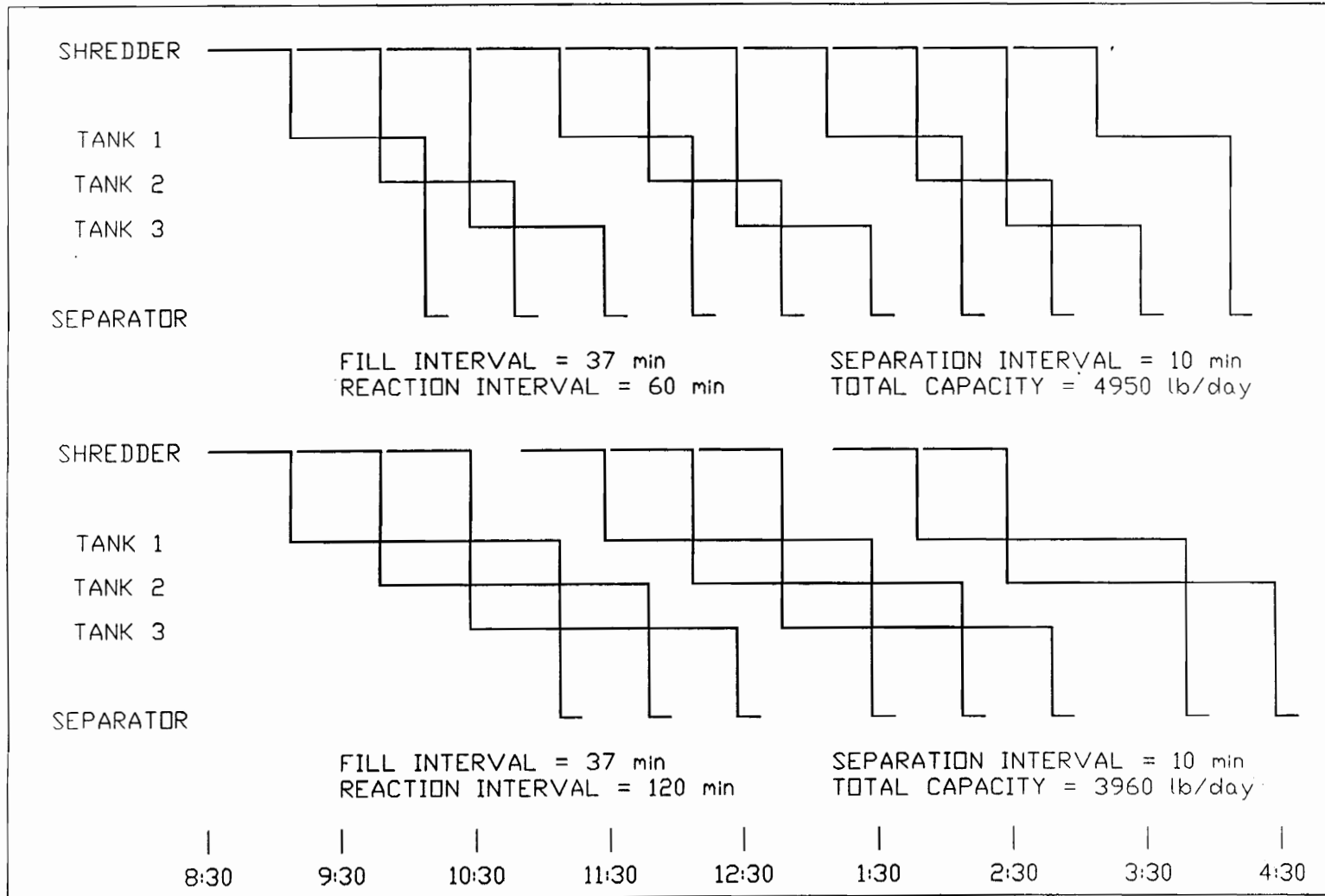
Figure 14. Process Diagram with 1100 lb/hr Shredder Throughput

CHAPTER 5
COMPONENT AND SYSTEM TESTS

The design is complete and component purchase has begun. In some instances it has been possible to examine the equipment at the manufacturing facility to determine its suitability for the bioremediation system. Other items can only be tested in conjunction with other components, or must be specially fabricated.

5.1   Size Reduction System

The suitability of the industrial shredder was determined at the manufacturing site by running thirty pounds of simulated medical waste through a slightly smaller shredder with the specified sizing screen. Examination of the shredded material shows that there is a size distribution that, on the whole, is acceptable for our application. The testing was recorded on videotape by members of the project team. It was noted that a 15-hp motor driving the smaller shredder could be easily jammed with layers of cardstock. It has been decided to specify the most powerful (40-hp) motor combination available in the 2330 size for our prototype (Figure 15). This size has been chosen based on the fact that much medical waste is stored or shipped in a standardized cardboard box of dimensions 18" x 18" x 24".

Further testing may reveal that a single 25-hp motor is sufficient to the task of shredding medical waste. The vendor indicated that throughput should be on the order of 800-1100 pounds per hour. Current estimates of system daily throughput are based on this estimate. A more rigorous test of mass throughput must be performed as soon as the system is available for testing. It will be useful to determine the throughput sensitivity to variations in the waste stream composition.

1600 SERIES

MODEL	W	A	B	L-1	L-2	D
1620	20	20	16	84	96	13
1630	20	30	16	90	102	13
1642	20	42	16	102	114	13
1648	20	48	16	108	120	13

	Single Drive	Dual Drive
Standard HP	10	20

2300 SERIES

MODEL	W	A	B	L-1	L-2	D
2324	30	24	23	84	96	23
2330	30	30	23	91	103	23
2342	30	42	23	108	120	23
2354	30	54	23	120	132	23

	Single Drive	Dual Drive
Standard HP	25	40

2800 SERIES

MODEL	W	A	B	L-1	L-2	D
2830	35	30	28	95	120	23
2842	35	42	28	107	132	23
2854	35	54	28	119	144	23
2866	35	66	28	131	156	23

	Single Drive	Dual Drive
Standard HP	50	75

3200

CONSULT FACTORY

Figure 15. Franklin Miller Shredders

One of the main reasons this particular shredder has been chosen is that it employs an especially effective bearing/seal cartridge that should prevent shredded material or moisture from reaching the gear housing. It is also meant to simplify standard maintenance. The extent to which this is true may be investigated by simply removing the cartridges (if it is truly that simple) and inspecting the gear housings for foreign particles after a number of test runs.

5.2   Pneumatic Conveying System

5.2.1   Overview of Experimental Setup

The effectiveness of pneumatic conveying and cyclone separation of medical waste was investigated by building a mock-up of the pneumatic loop, feeder and tank. A diagram of the experimental setup is given in Figure 16. The apparatus was designed to test two separate facets of the pneumatic conveying concept. First, the belief that the curvature of the cylindrical tank wall could provide adequate cyclone separation must be verified. Second, the pressure losses associated with transporting shredded medical waste had to be determined. These goals were accomplished by applying scaling laws (where applicable) to measurements taken of the mock-up.
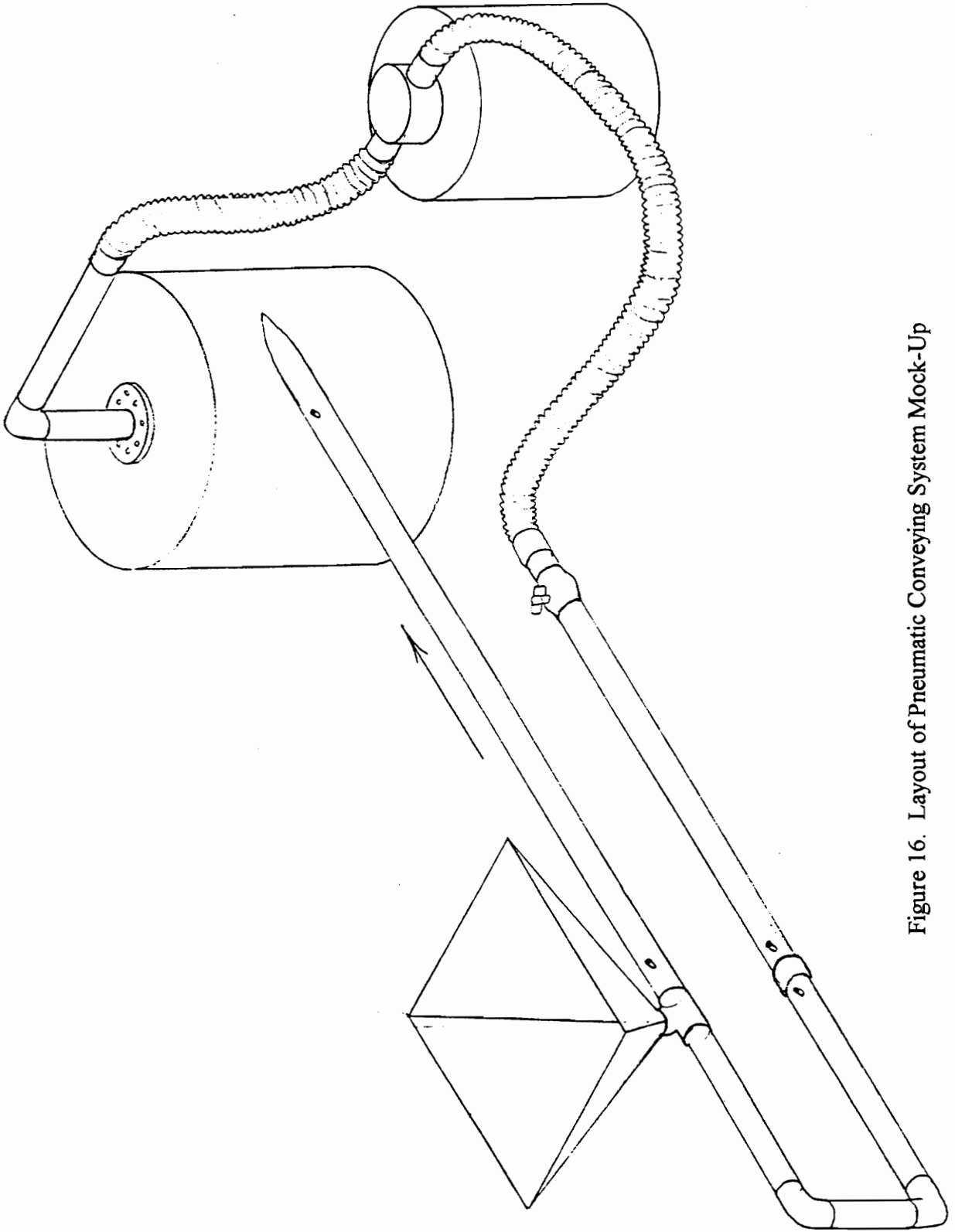
Figure 16. Layout of Pneumatic Conveying System Mock-Up

5.2.2 Experimental Apparatus and Measurements

The mock-up (Figure 17) was constructed from readily available materials. The components used were as follows:

Prime Mover: Sears 20 gallon Shop-Vac (3.75 hp)
Tank: 55 Gallon Drum with epoxied tangential PVC fitting
Piping: Two-inch schedule 40 PVC pipe
Throttle Valve: Two-inch PVC ball valve (1/4 turn)
Feeder: PVC Reducers and Tee-fitting

The thin-plate orifice (used to measure air velocity) was of a beta-ratio of 0.5 and pressure measurements were taken using the 1/2D : D standards [15], with appropriate upstream and downstream flow straighteners.

The validity of low-curvature cyclone separation was demonstrated by observing the material entering the tank. Even at speeds as low as 10 m/s (below the predicted saltation velocity for the material) visible particles remained in contact with the tank walls. More than twenty pounds of material (the material from the size reduction test mentioned above) were conveyed in this manner without powering down the fan. At the end of the experiment the Shop-Vac was disassembled and the filter inspected. No particles large enough to be detected by the human eye had escaped the tank. Separation results were scaled up to a larger tank by assuming a full-scale inlet velocity of at least 20 m/s. Centripetal acceleration was then matched in the mock-up system by controlling the velocity in the small-scale tank $\left(A_{c,\,full-scale} = A_{c,\,mock-up} = V_{inlet}^2 \Big/ r_{tank} \right)$.

Ac = centripetal acceleration

V = inlet velocity

r = tank radius

TAPS FOR
VELOCITY
MEASUREMENT

FLOW
STRAIGHTENER

FLOW
STRAIGHTENER

ORIFICE

D

D/2

PRIME MOVER

TANK

TAP FOR TANK
STATIC-PRESSURE
MEASUREMENT

FEEDER

LOW PRESSURE TAP
FOR MANOMETER "A"

L

HIGH PRESSURE TAP
FOR MANOMETER "A"
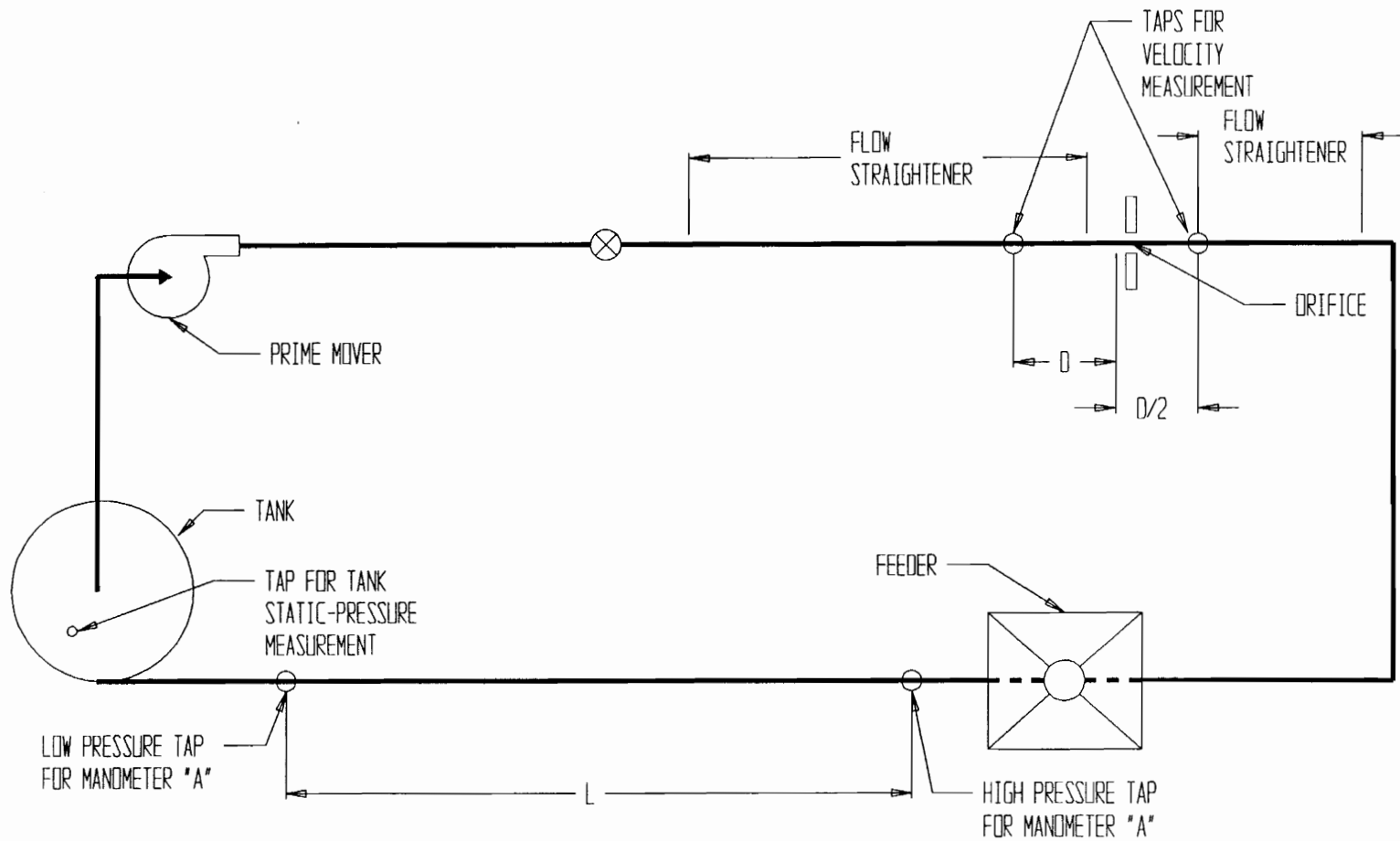
Figure 17. Pneumatic Conveying System Experiment

Pressure losses were measured at different velocities in hopes that the physical characteristics needed to apply certain empirical models could be applied. This proved not to be the case. Enough data was collected, however, to make a good estimate of the pressure loss in the final scaled-up system. Pressure drops (measured with a water manometer) were collected along both vertical and horizontal pipe lengths.

5.2.3   Calculations and Conclusion

The theories applied in scaling the experimental results to a full-size system were found in Marcus, Leumg, Klinzing and Rizk [16, pp. 233]:

$$\frac{\Delta P}{\Delta L} = \frac{\mu \lambda_z \rho V^2}{2D}$$

$\dfrac{\Delta P}{\Delta L}$ = pressure loss per unit length

μ = mass loading ratio

λ_z = solids friction factor

ρ = particle density

V = flow velocity

D = pipe diameter

The pressure drops associated with horizontal conveying are actually higher than those for vertical conveying due to reduced particle-wall interaction. As such, it has been assumed that all pipe lengths in which solids would be conveyed were horizontal. The parameter λ_z is a relatively insensitive function of the Froude number [16, pp. 223], and has been assumed to be constant for the purposes of scaling. Pressure drop per unit length scaled to a 4" diameter and 30 m/s velocity (with associated drop in mass load ratio μ) can be

used to modify the above equation to predict pressure loss per unit length from the measured quantities:

$$\frac{\Delta P_z'}{\Delta P_z} = \frac{\left(\frac{\mu'}{\mu}\right)\left(\frac{V'}{V}\right)^2 \lambda_z \rho}{2\frac{D'}{D}}$$

Primed parameters indicate characteristics of the full-scale system. Therefore:

$$\Delta P' = \frac{3}{8}\Delta P$$

A number of implicit safety factors have been included in the scaling. Dependence on Froude number, reduced wall interaction (lower $\frac{d}{D}$) and the inclusion of vertical pipe sections all combine to lower the actual pressure loss a bit further.

The test apparatus demonstrated that material could be effectively transported pneumatically. The cyclone separation is effective with particles of this nature, even in the absence of water to entrain material entering the tank.

A bridging problem was noted at the feeder inlet. Although the conveyed material was added at a somewhat inconstant rate, it was never added so fast that dense-phase flow should have occurred. Material tended to clog the acceleration zone at the interfaces between reducers. A more thorough investigation of feeder and acceleration zone geometries is necessary to avoid this problem in the full-scale system. The much lower mass-loading ratio specified in the full-scale prototype should help to eliminate the possibility of bridging in the acceleration zone. It has been suggested that shock-mounting the feeder to the shredder would provide enough vibration to eliminate any bridging problems.

The mock-up was able to transport small pieces of metal and glass even in the absence of less dense materials to act as a vehicle. Wet material was successfully conveyed, though it is unclear exactly how pressure drop was affected. A full-scale prototype will allow the direct measurement of pressure loss in the piping and its dependence on mass flow rate and composition.

The estimated operating point for the system's prime mover is 530 cubic feet per minute at a pressure differential of 12 inches of water suction. This pressure estimate may be a high because the effect of changing the ratio of particle size to pipe size d/D was not taken into account. Theoretically, this change should reduce losses about bends and elbows, and in the acceleration zone.

5.3   Agitation Characteristics

Philadelphia Mixer Co. was sent some of the shredded waste from the size-reduction tests in order to determine the mass ratio at which that material could be effectively agitated. It was determined that a propeller agitator with a 5-hp drive could agitate no more than a 9% slurry. Even at higher powers, a denser slurry would develop dead zones in which material was not effectively mixed. The results of this test apply only to cylindrical mixing tanks on the order of the specified 600 gal vessels.

The tests performed by Philadelphia Mixer do not take into account the effect of the Cellulase enzyme on cellulose, the primary component in most medical waste streams. It is believed that hydrolyzing the fibrous materials will significantly alter the apparent viscosity of the material, increasing the amount of material that can be processed in a single tank. The extent to which this is true, and the rate at which the reaction proceeds

must be determined empirically in the full-scale prototype. To a large degree, total system throughput will depend on the results of this series of tests. Enzyme concentration may prove to be a significant factor in the efficient hydrolyzation of the waste.

5.4 Slurry Pump

It is assumed that the Warman Cyclone pump, once primed, will be capable of pumping the digested, disinfected slurry to the separator. Should the slurry prove too thick or cohesive to pump easily, or not liquid enough to quickly flood the pump inlet, it will be necessary to dilute the slurry as it is pumped. This does have some advantages. Since it is undesirable to deliver large quantities of hot water directly to the sewer, cutting the slurry with an equal quantity of cold city water solves a potential problem. The slurry pump flow rate will have to be choked to something manageable by the solid-liquid separator.

5.5 Separator

The specified solid-liquid separator was tested at the fabrication site by pouring a quantity of digested simulated medical waste across the screen to observe the level of drainage. All the indigestible items and the vast majority of hydrolyzed fibers were effectively screened out. Those few fibers that made it through the screen were of a size to cause no difficulty to any type of pump or valve. The screw-press is expected to perform equally well, but has not been tested by team members (although videos have been viewed). A utility employing a larger version of the rotary-screen/screw-press combination was toured. The separator seemed to be very effective and the personal in charge of the equipment claimed no problems.

It is believed that no further component testing is necessary for this item. It must be

purchased before full-scale system testing can occur. The 600 gallons of slurry produced in every test of the conveying system, shredder or agitator must be disposed of in some manner. This will be an excellent opportunity to note the sensitivity of the separator to varying slurry concentrations and compositions.

5.6 Control System

The Allen-Bradley SLC500 and accompanying programming and interface software were loaned to the development team by Allen-Bradley, Inc. of Roanoke for an evaluation period. There is little doubt that the controller is capable of doing the job. It will be necessary to develop a large amount of code to implement the necessary process strategy. It is now believed that a somewhat complex interface package, GENESIS, will prove invaluable in developing a self-explanatory visual operator interface. The programming of the SLC is done in a unique programming environment called ICOM. No further component testing is necessary for this item. Nonetheless, a large amount of time will be needed to become familiar with the software. It is suggested that these products be purchased immediately. Using the SLC and interface software to control the system experiments will allow the programmers to determine a learning curve and time investment for development of the final control system implementation.

The ICOM programming environment contains an emulator for the SLC500 which allows testing of the control scheme given different conditions. Almost any abnormal condition (i.e. leak, failed motor, etc.) can be detected as some unique combination of instrument register values. For instance, if the pH in a tank is not changing when acid is added, it may be that the acid is not actually reaching the tank, which may imply that the acid line has a leak. The pump would be shut off immediately and the operator notified. These

conditions can be emulated to ensure that the control scheme responds properly. Determining what combinations indicate a potential problem will dictate where more extensive instrumentation is necessary to detect system and component failures. It is strongly recommended that this work be initiated as soon as possible. The safety of this system depends entirely on the effectiveness of the control scheme in detecting and correcting faults, and of the interface software in indicating them to the operator.

5.7   Installation

The final phase of testing requires the installation of the system in a hospital, where it will be determined whether or not the system meets requirements of operator-friendliness, safety and simplicity. Actual throughput, taking the operator into consideration, can be measured and possibly improved. Any failures will lead to system and component reevaluation and will result in redesign, if warranted. Operators will be asked for their input, so that the design can be improved ergonomically. Unexpected expenses can be taken into account and predicted operating expense can be validated. Actual cost of installation can be recorded and modified for future estimates.

Lewis-Gale Hospital is a likely site for the first installation. They are eager to replace their incinerator with a system which is economically, environmentally and ergonomically superior. A likely installation site, adjacent to the existing incinerator and one floor below the waste-storage room has been suggested. This will allow delivery of the bags/boxes of waste directly into the hopper via an existing chute-and-hatchway. The available fourteen foot ceiling is more than adequate for our needs.

It is suggested that project personnel work closely with the subcontractors who will be enclosing the installation space and installing the process equipment. Utilities must be adequate for the system. The final delivery system specifications should be developed concurrently with the planning of the space enclosure next to the incinerator. A door-and-chute system currently delivers bags to the incinerator area. It is likely that it can be modified or copied to serve the bioremediation system.

Services that must be available to operate the system as specified include:

Power
- 3-phase
- 230 volts (460 is useful but not absolutely necessary)
- A service potential of 500 Amps (peak power consumption before hot water heating)

Water
- 50 degrees Celsius
- 60 gallons per minute, up to 600 gallons.

Sewer
- 60 to 100 gallons per minute, up to 1000 gallons

Waste Removal
- 4,000 to 8,000 pounds of waste each day (depends on system usage)

Extensive records must be kept regarding the performance of the system to facilitate the licensing process. In the event of any failure, impact on system performance, hospital routine, operator safety and the environment must be fully documented so that this and other difficulties can be prevented in the future.

Appendix A -- Operating Costs

The operating cost for every conceivable system can be roughly calculated based on assigned utility costs. Consumable materials costs may then be added to give a more realistic estimate of the cost of operation per pound of processed waste. Finally, peripheral costs such as manpower and maintenance may be estimated and added into the overall cost of operation. It is important to itemize this information so that those factors which are major influences in overall operating cost are recognized. The bioremediation system operating cost has been analyzed based on the following assumptions:

- All energy is electrical and costs 10 cents/KWH
- Hot water must be heated from 20 to 50 degrees Celsius (electric heating)
- Acetic acid costs $14.50/gallon
- Bulk enzyme mixture costs 3.80/lb and is consumed at 2% by weight of reacting slurry
- Hauling costs $50.00/ton of processed materials
- Manpower and maintenance costs are not included
- Cost per pound has been determined by calculating operating cost per 1-shift work day and dividing by estimated daily throughput

The operating costs have been broken down by operations groups so that a particular group may be accurately scaled up or down as more accurate information becomes available. For instance, a new operating cost may be immediately calculated based on a change in local power costs or a better cost estimate for hot water.

A1: Operating cost for 800 lb/hr shredder (utilities only)

A2: Operating cost for 800 lb/hr shredder (utilities and consumable materials)

A3: Operating cost for 1100 lb/hr shredder (utilities only)

A4: Operating cost for 1100 lb/hr shredder (utilities and consumable materials)

Operating Cost
$0.042 Per Pound Waste

Assuming 800 lbs/hr throughput

Motor Power (11.9%)

Heating Power (14.4%)

Water (1.4%)

Hauling (72.3%)
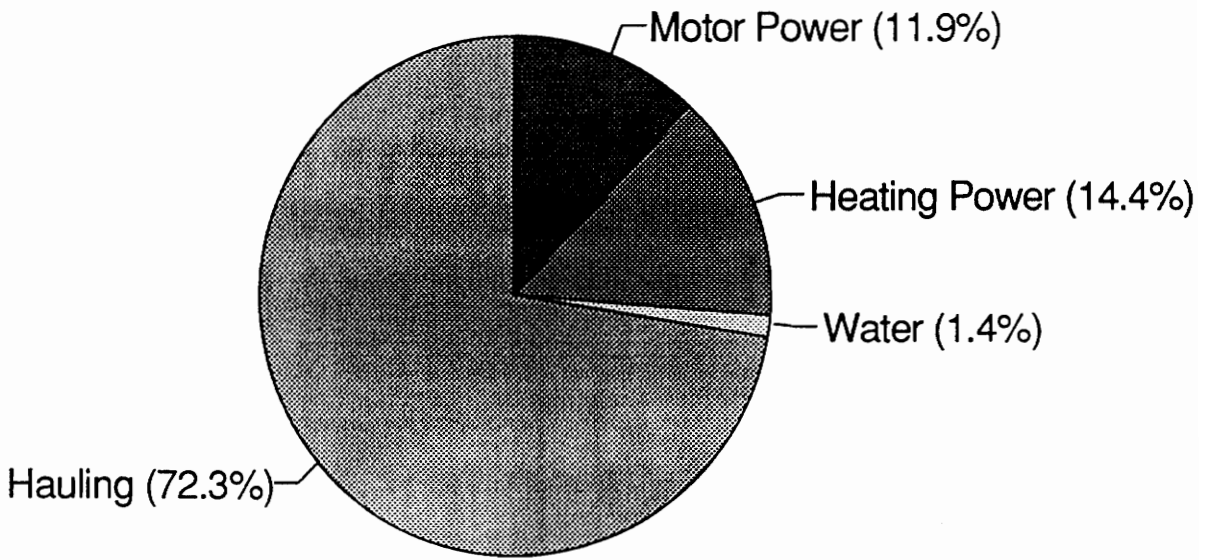
Operating Cost
$0.153 Per Pound Waste

Assuming 800 lbs/hr throughput

Heating Power (3.9%) — ⌐ Water (0.4%)

Hauling (19.5%)

Motor Power (3.2%)

Acid (4.9%)

Enzyme (68.1%)
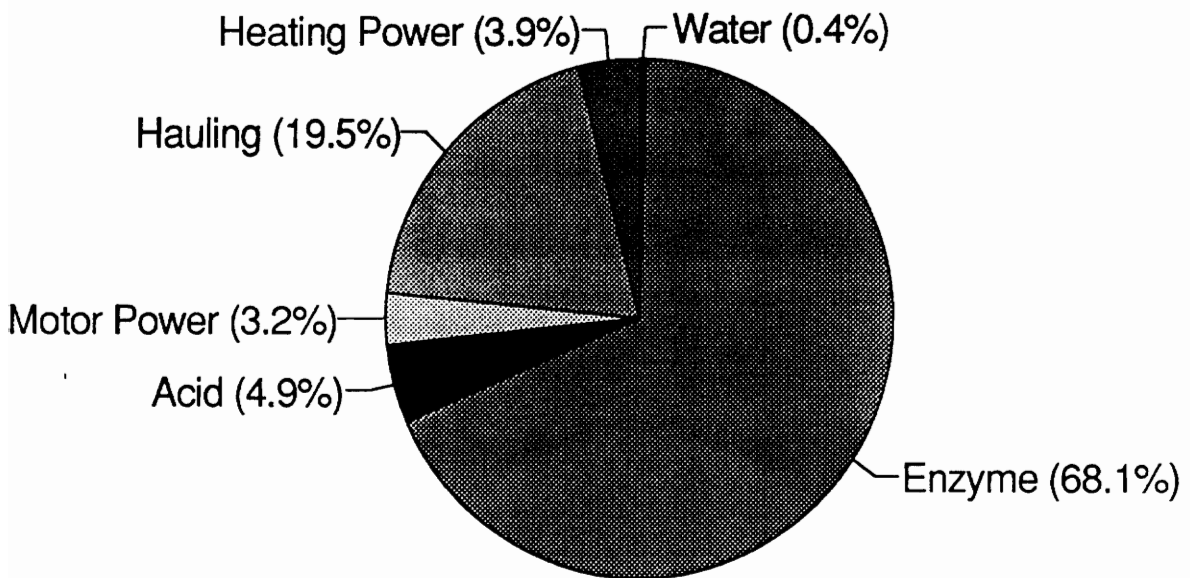
Operating Cost
$0.039 Per Pound Waste

Assuming 1100 lbs/hr throughput

Motor Power (9.5%)

Heating Power (12.2%)

Water (1.2%)

Hauling (77.1%)
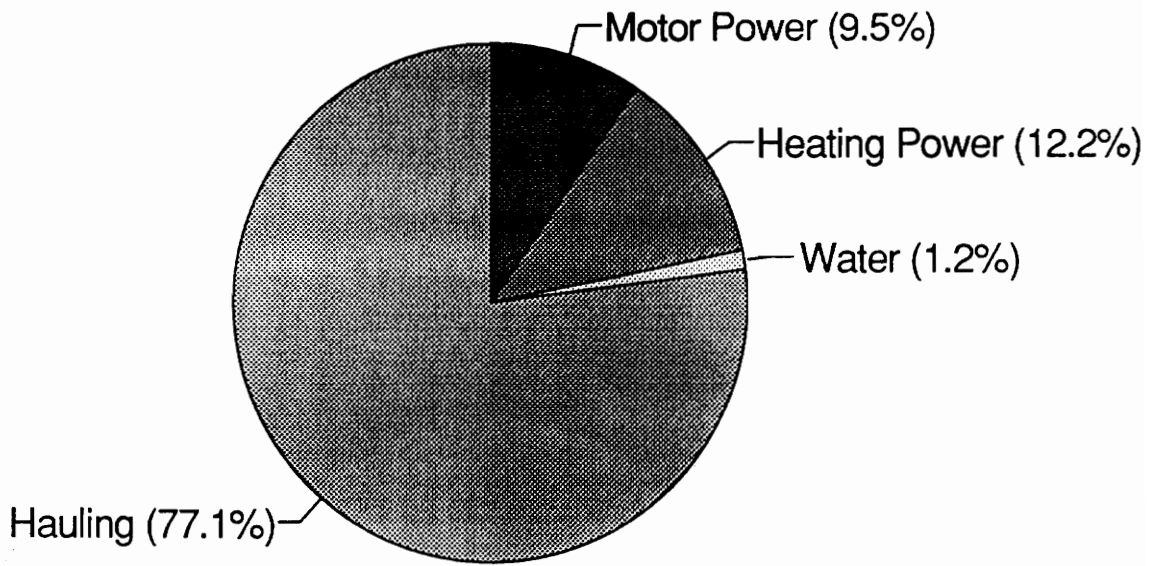
Operating Cost
$0.151 Per Pound Waste

Assuming 1100 lbs/hr throughput

Hauling (19.9%)

Water (0.3%)
Acid (5.0%)

Heating Power (3.2%)
Motor Power (2.5%)

Enzyme (69.2%)
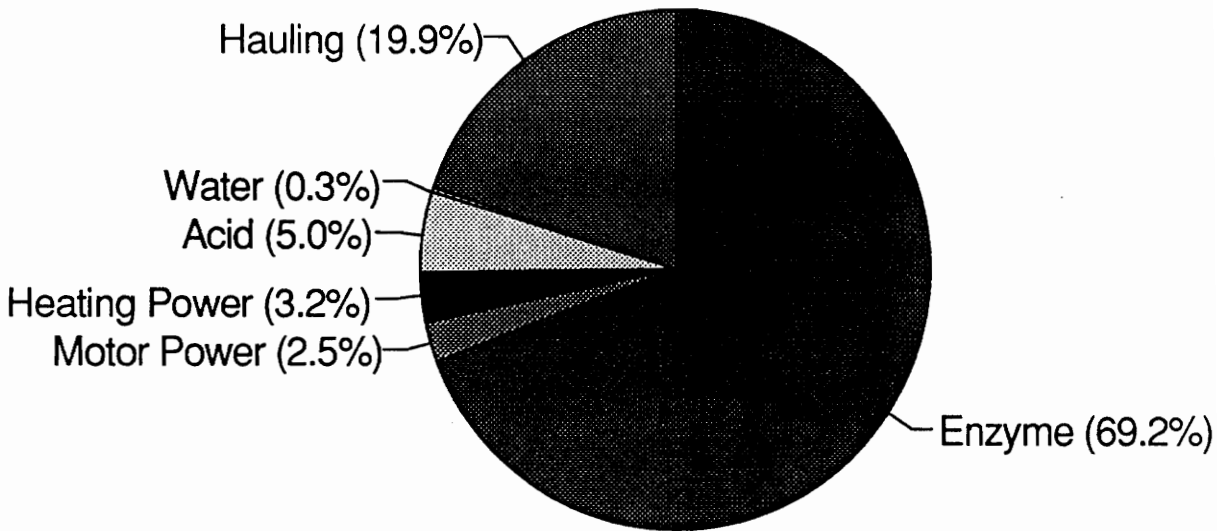
Appendix B -- Component Costs

The overall cost of system components has been determined from vendor quotes, catalog prices and telephone or written estimates. Estimates comprise a large part of the price information on the following bill of materials. It is believed that the actual component cost of the system will fall within ten percent of the estimated cost.

Installation costs cannot be accurately assessed for this system. Dependence on available utilities and regulations regarding electrical and plumbing hookups, as well as the amount of site-preparation needed will cause the installation costs to vary from hospital to hospital.

Item	Num.	Unit Price	Total Price
--- Shredding System			
Shredder	1	$39,000.00	$39,000.00
Hopper	1	$2,000.00	$2,000.00
Negitive Pressure Fan	1	$2,625.00	$2,625.00
HEPA Filter and Housing	4	$1,382.00	$5,528.00
Shredding System Cost		$49,153.00	
--- Pumps			
Slurry Pump	1	$7,715.00	$7,715.00
Pumping System Cost		$7,715.00	
-- Pnuematic Conveying System			
Blower	1	$1,000.00	$1,000.00
--- Metering System			
72 gal holding tanks with clamped top	2	$2,117.00	$4,234.00
Domed Bottom Polyethylene Tank	3	$297.25	$891.75
Cover for Tank	3	$25.22	$75.66
Acid/Base Metering Pump	5	$1,474.00	$7,370.00
Drum Pumps	1	$170.00	$170.00
Motor for Drum Pump	1	$215.00	$215.00
Metering System Cost		$12,956.41	
--- Tanks			
Reaction Tank	3	$6,742.00	$20,226.00
Agitators	3	$8,037.00	$24,111.00
Tank System Cost		$44,337.00	
--- Control System			
SLC 500 Central Processor Unit	1	$665.00	$665.00
10 slot rack - Modular hardware style	1	$395.00	$395.00
EEPROM for 4K user instructions	1	$285.00	$285.00
Battery for RAM memory retention	1	$65.00	$65.00
Power Supply - Rack Mount - 15 AMPS	1	$355.00	$355.00
ICOM Programming Software	1	$1,450.00	$1,450.00
Genesis SCADA Package	1	$3,500.00	$3,500.00

Analog Contactor Card	1	$260.00	$260.00
Analog Card, 4 inputs	1	$565.00	$565.00
Analog Card, 4 outputs	1	$650.00	$650.00
AC output card	3	$355.00	$1,065.00
AC input card	3	$255.00	$765.00
AC Contactors	24	$156.00	$3,744.00
Full Voltage Starter, 2 HP motor	3	$105.00	$315.00
Full Voltage Starter, 1/4 HP motor	1	$174.00	$174.00
Full Voltage Starter, 1 HP motor	1	$195.00	$195.00
Control System Cost		$14,448.00	
--- Instrumentation			
-- Thermocouple Assembly			
Industrial Thermocouple with			
a cast iron proctection head	3	$47.00	$141.00
Standard Threaded Well	3	$26.50	$79.50
Minature Temperature Transmitter	3	$140.00	$420.00
Temperature System Cost		$640.50	
-- pH Assembly			
pH Electrode	3	$110.00	$330.00
Mounting Assembly with ATC	3	$298.00	$894.00
Digital Panel pH Transmitter	3	$215.00	$645.00
pH System Cost		$1,869.00	
Liquid Level Control	11	$328.00	$3,608.00
Instrumentation Cost		$6,117.50	
--- Separator			
Separator	1	$25,000.00	$25,000.00
--- Disenfection System			
Cyclone Aerosol Applicator	1	$406.00	$406.00
--- Piping/Valves			
Air Acutation System	1	$1,985.00	$1,985.00
-- Metering Piping/Valves			

3/8" Soleniod Actuated Valves	6	$164.00	$984.00
3/8" Manual Valves	4	$23.00	$92.00
1" Solenoid Actuated Valves	3	$235.00	$705.00
1" Manual Valves	2	$25.00	$50.00
3/8" Stainless Steel Tubing	180	$0.86	$154.80
1" Stainless Steel Tubing	90	$1.06	$95.40
-- Valves			
4" Shuttle Valves	2	$3,150.00	$6,300.00
3" Gate Valves	3	$935.00	$2,805.00
3" Manual Valves	1	$308.00	$308.00
2" Manual Valves	1	$238.00	$238.00
-- Piping Components			
-- 4" Components			
45 deg elbow	2	$3.00	$6.00
90 deg elbow	3	$3.00	$9.00
Flange with bolt/gasketing kit	5	$3.20	$16.00
Y Connector	5	$3.10	$15.50
Long Sweep Elbows	2	$0.35	$0.70
Blind Flange	2	$21.03	$42.06
-- 3" Components			
Flange with bolt/gasket kit	4	$3.20	$12.80
Y connector	3	$3.10	$9.30
Blind Flange	1	$19.03	$19.03
-- 2" Components			
Flange with Bolt/Gasket Kit	2	$1.94	$3.88
Elbow	3	$0.35	$1.05
-- Piping			
4" Pipe	100	$0.75	$75.00
3" Pipe	40	$0.60	$24.00
2" Pipe	20	$0.50	$10.00
Piping System Cost		$13,961.52	
		System Total	$175,094.43
		2% Misc Cost	$3,501.89
		Overall Cost	$178,596.32

Appendix C -- Competing Disinfection Systems

The following tables have been adapted from the work of Reinhardt and Gordon [4]. They are meant only to provide a qualitative comparison of system attributes. Other legal or regulatory regulations may apply in different states. Italicized cost items in table C3 indicate a cost (calculated by the author) that differs substantially from the values given in [4].

C1.   System Comparisons -- Regulatory Requirements

C2.   System Comparisons -- System Operations

C3.   System Comparisons -- Quantitative Breakdown

Table C1. System Comparisions--Regulatory Requirements

Factor	Steam Sterilization	Incineration	Hammermill/Chemical	Steam/Compaction	Microwave/ Shredding ABB	Bioremediation	Comments
Applicable environmental regulations	Wastewater	Air emissions, ash disposal, wastewater	Wastewater	Wastewater	None	Wastewater	
Releases to air	Low risk via vent	High risk via emissions	Low risk via HEPA filter	Low risk via vent	Low risk via vent	Low risk via HEPA filter	
Releases to water	Low risk via drain	Low risk via scrubber water	Moderate risk via wastewater*	Low risk via drain	Low risk (evaporation)	Moderate risk via wastewater*	*B.O.D, C.O.D and suspended solids
Disposal of residue	Sanitary landfill; potential problem with red bags	Ash may be a hazardous waste; if so, to RCRA-permitted landfill*	Effluent to sanitary sewer; residue to sanitary landfill**	Same as for steam sterilization	Residue to sanitary landfill	Effluent to sanitary sewer; residue to sanitary landfill**	*Special Waste **Physical/ chemical attributes must meet EPA requirements
Permitting requirements	None	For siting, air emissions	None	None	None	None	
Capital costs	Low	High	Moderate	Low	High	Low	
Labor costs	Low	High	Moderate	Low	Moderate	Moderate	
Operating costs	Low	High	Moderate	Low	Moderate	Low	
Maintenance costs	Low	High	Moderate	Low	Moderate	Low	
Downtime	Low	High	Low to moderate*	Low	Moderate to high	Low	*Local Availability

86

Table C2. System Comparisions--System Operations

Factor	Steam Sterilization	Incineration	Hammermill/ Chemical	Steam/Compaction	Microwave/Shredding ABB	Bioremediation	Comments
Applicability	Most infectious wastes*	Almost all infectious wastes	Most infectious wastes*	Most infectious wastes*	Some infectious wastes*,**	Most infectious wastes*	*Not chemical/ radioactive/ pathological **Not approved for syringes, blood and body fluids
Equipment operation	Easy	Complex	Moderately Complex	Easy	Moderately Complex	Moderately Complex	
Operator requirements	Trained	Highly Skilled	Trained	Trained	Trained	Trained	*Licensed for pressure vessel operation
Need for waste separation	To eliminate non-treatable wastes	None	To eliminate non-treatable waste. For proper feeding	Same for steam sterilization	To eliminate non-treatables, syringes, blood and body fluids	Same for steam sterilization	
Effect of treatment	Appearance of waste unchanged	Waste burned	Waste shredded and ground	Minimum change in appearance	Waste shredded only	Waste shredded and chemically broken down*	*Plastics unaffected
Volume reduction	30%	85%-95%	up to 85%	50%	up to 85%	up to 85%	
Occupational Hazards	Low	Moderate	Moderate	Low	Low	Low	
Potential sidebenefits	None	Energy Recovery	None	None	None	Possible mass reduction	
Onsite/Offsite location	Both	Both	Both	Both	Onsite	Both	

Table C3. System Comparisions--Quantitative Breakdown

Technology	Advantages	Disadvantages	Capacity lbs/hr	Volume Reduction	Capital Costs	Operational Costs cents/lb	Residue Dispoasl cents/lbs
Incineration	Accepted procedure Volume reduction 10:1 Waste unrecognizable Heat Recovery	Operational problems Temperature variability Licencing & permitting Air emission problem Ash disposal	1,200	>90%	$2,000,000	8.0-9.0 cents	2.0 cents *5.0 - 10.0 cents*
Mechanical/ Chemical Treatment	Acceptance by landfill Waste unrecoginizable Volume reduction 8:1 Rapid on demand process No odor/air emissions Controllable & flexible	Personnel training Consumable parts Suspended Solids Storage of chlorine Some regulatory barriers Sewer permit required	1,000	80%	$350,000	4.4 cents	0.8 cents *2.0 - 3.0 cents*
Steam/ Compaction	Accepted procedure Volume reduction 5:1 Easy operation No double handling No air emission No licensing or perimtting	Landfill acceptability Long cycles required Validate & Monitor required Odor Problem if located outdoors (freezing potential)	200	50%	$125,000	3.5-4.0 cents	2.0 cents
Microwave/ Shredding	Waste unrecoginable Volume reduction 8:1 No liquid effulent No air emissions Easy operation Recyclable byproduct	Consumable Parts Metallic content: < 1% moisture: < 10% of weight Temperature hold time uncertain Odor	500	80%	$650,000	7.0-10.0 cents	*2.0 - 3.0 cents*
Bioremediation	Acceptance by landfill Volume reduction Waste unrecognizable Rapid on demand process No odor or emmisions Controllable and flexible	New technology Acid/Base storage Suspended solids Validate & moniter equipment	800-1100	80% - 90%	$190,000 Before installation, overhead and profit	1.5 - 2.0 cents Before Enzyme Costs	2.0 - 3.0 cents

Appendix D -- Vendors and Manufacturers

Blenders

> Patterson Industries, Ltd.
> 250 Danforth Road
> Scarborough, Ontario M1L3X4
> (416) 694-3381

> EMI, Inc.
> Heritage Park Road
> P.O. Box 912
> Clinton, CT 06413
> (203) 669-1199

> Scott Equipment Co.
> 603 Fourth Avenue
> New Prague, MN 56071
> (800) 333-9519

Conveyor Belts

> The Rapat Corporation
> Hawley Industrial Park
> Hawley, MN 56549
> (302) 762-8411

> Buck-El, Inc.
> 564T Central Avenue
> Murray Hill, NJ 07974
> (908) 464-0700

> W.A. Powers Company, Inc.
> 125-A South Main Street
> Fort Worth, Texas 76104
> (800) 792-1243

Chopper Pumps

Vaughan Company, Inc.
364 Monte-Elma Road
Montesano, WA 98563
(206) 249-4042

Dispersers

Shar, Inc.
P.O. Box 9196-TR
Ft. Wayne, IN 46899
(219) 432-5312

Lift Mechanisms

United Tools and Stamping
22400 County Road 14
P.O. Box 1352-T
Elkhart, IN 46515
(219) 294-3780

Vestil Manufacturing Co.
P.O. Box 507-A
Angola, IN 46703
(800) 348-0868

Abal Material Handling, Inc.
P.O. Box 11965
Roanoke, VA 24022
(800) 572-3052

Misters/Foggers

Curtis Dyna-Products Corporation
17335 U.S. Highway 31 North
Westfield, IN 46074
(317) 896-2561

Zep Manufacturing Company
1702 Rubley Lane
Salem, VA 24153
(703) 387-1789

Mixers

Philedelphia Mixers Corporation
1223 East Main Street
Palmyra, PA 17078
(717) 838-1341

Jaygo, Inc.
40 Whitney Road
Mahwah, NJ 07430
(201) 848-0200

Warman International, Inc.
2701 South Stoughton Road
P.O. Box 7610
Madison, WI
(608) 221-2261

Presses

Dontech, Inc.
76 Center Drive
Gilberts, IL 60136
(708) 428-8222

The Dupps Company
P.O. Box 189
Germantown, OH 45327-0189
(513) 855-6555

American Screw Press Inc.
P.O. Box 600
306 Ramapo Valley Road
Oakland, NJ 07436
(201) 337-6382

Pumps - General

Gelber Industries, Inc.
5101 Governor Printz Blvd.
Wilmington, DE 19809
(800) 548-7867

Pumps - Slurry

Warman International, Inc.
2701 South Stoughton Road
P.O. Box 7610
Madison, WI
(608) 221-2261

Screw Conveyors

AFECO
Highway 18 East
P.O. Box 280
Algona, IOWA 50511
(515) 295-7234

Screw Conveyor Corporation
700 Hoffman Street
Hammond, IN 46327
(219) 931-1450

Shredders

Franklin Miller, Inc.
60 Okner Parkway
Livingston, NJ 07039
(201) 535-9200

Hi-Torque Shredder Co.
2445 Nevada Avenue North
Minneapolis, MN 55427
(800) 328-6887

Excalibur Shredding Systems
2497 U.S. 23
P.O. Box 169
AuGres, MI 48703
(800) 394-6988

Traveling Screens

Dontech, Inc.
76 Center Drive
Gilberts, IL 60136
(708) 428-8222

General Kinematics
777-T Lake Zurick Road
Barrington, IL 60010
(708) 381-2240

Reynold, Inc.
Bourne Street
Westfield, NY 14787
(716) 326-3121

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