Remediation Strategies for Source Materials and Contaminated Media at Manufactured Gas Plant (MGP) Sites

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Prepared by
REMEDIATION TECHNOLOGIES, INC.
3040 William Pitt Way
Pittsburgh, Pennsylvania 15238-1359

Principal Investigator
D. V. Nakles

Prepared for
MGP Task Force
Edison Electric Institute
701 Pennsylvania Avenue NW
Washington, DC 20004

Task Force Representatives
H. L. Hoffman
G. J. Mon
C. R. Bozek

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

EPRI Project Manager
I. P. Murarka

Environment and Health Business Unit
Strategic Development Group

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REPORT SUMMARY

This report contains information on remediation technologies that can be used to manage source material and contaminated media at manufactured gas plant (MGP) sites. It describes each technology, discuses limitations, and defines the key factors that should be taken into account before selecting the technology for use at a given site.

Background

The challenges of MGP site remediation, while unique in some respects, are not unlike those associated with other sites with hydrocarbons from oil, creosote, or chemical manufacturing. The utility industry, therefore, can benefit from other industries such as chemical manufacturing, wood treating, and petroleum refining that have viable remediation technologies that can be adapted to MGP sites. However, utilities will have to gain site-specific experience for each remediation technology to complete a proper evaluation of its performance capabilities, economics, and reliability.

Objectives

To streamline the identification and selection of potential remediation technologies for the management of MGP sites; to identify the remediation technologies potentially applicable to addressing site specific remediation goals.

Approach

The project team developed a generalized remediation strategy for MGP sites that consisted of a mixture of in situ and ex situ management techniques for both source material and contaminated media such as soil, groundwater, and sediment. For each remedial technology, they developed a process flowsheet and an overview of its basic principles of operation, reviewed the advantages and disadvantages of application of the technology to MGP site residuals, and summarized the results of the treatment of MGP site residuals.

Results

The study indicated that:

- The technologies to treat contaminated water from MGP sites are reasonably well understood. A total of 11 conventional unit operations were identified that are capable of removing the target contaminants from water, depending upon the specific discharge requirements of a given site.

- The technologies to cost-effectively treat source materials and contaminated solids at MGP site are not as well developed as groundwater treatment. Proven treatment options appear to be limited to thermal treatment and landfill disposal. However, coburning in a utility boiler; stabilization; and recycle alternatives such as the production of asphalt, aggregate, brick, or cement will soon be available. Aeration, biological treatment, aqueous/solvent extraction, and chemical treatment are very sensitive to the nature of the solid-contaminant matrix; and their performance will vary from site to site. Site-specific treatability studies and/or on-site field demonstration tests will be required to establish the applicability of these technologies to any given site.
- Knowledge of in situ containment technologies is derived from the general construction industry, although MGP site applications have not been thoroughly examined. In situ treatment technologies have not been applied extensively under diverse conditions and represent evolving approaches to MGP site remediation. Since the efficiency of in situ technologies is not well understood, it is important to specify explicitly how success will be measured prior to their use.

EPRI Perspective
This study provides the utility industry with existing information on remediation technologies that will streamline the development of management strategies for source material and contaminated media at MGP sites. It is intended to serve as a site remediation reference rather than a step-by-step site remediation manual. The document will be updated as new remediation technologies are developed and existing remediation technologies are enhanced and demonstrated at MGP sites.

TR-103811

Interest Categories
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Land and water quality–chemistry and physics

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MGP waste
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Remediation technology

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ABSTRACT

This report contains information on remediation technologies that can be used to manage source material and contaminated media at manufactured gas plant (MGP) sites. Source material has been defined as free-phase hydrocarbons or tars and purifier box wastes. Contaminated media include soil, sediment, and groundwater which have been in contact with source material and which contain contaminants that are characteristic of the source material, i.e., volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), phenolic compounds, cyanide, and selected metals.

The remediation technologies described in this report were identified based upon their potential applicability to MGP site residuals, their commercial availability, and/or their previous full-scale applications at MGP or related sites such as petroleum refineries, wood treating facilities, or by-product coke manufacturing facilities. In this context, commercial availability means that the technology can be obtained from multiple vendors and can be incorporated into a full-scale site remediation. The major components of each technology are described and the use of the technology at an MGP site, including its advantages and limitations, are discussed. In addition, the key factors that influence the selection and performance of the technology are also presented.

ACKNOWLEDGMENTS

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INTRODUCTION

This report contains information on remediation technologies that can be used to manage source material and contaminated media at manufactured gas plant (MGP) sites. Source material has been defined as free-phase hydrocarbons or tars and purifier box wastes (i.e., spent oxide box wastes). Contaminated media include soil, sediment, and groundwater which have been in contact with source material and which contain contaminants that are characteristic of the source material, i.e., volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), phenolic compounds, cyanide, and selected metals.

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This report is organized as follows. Section 2 provides an overview of the scope and limitations of this report to ensure that the reader understands what information is contained in the report, how it was developed, and how it should be used. Section 3 presents a general discussion of the overall remediation strategies which may be utilized to manage an MGP site. Brief comments are also provided regarding some of the more important factors that influence the development of these strategies. Sections 4, 5, and 6 present specific *ex situ* and *in situ* remediation technologies for use at MGP sites for contaminated water, source material, and contaminated solids. Sections 4 and 5 discuss *ex situ* treatment of contaminated water and source material/contaminated media, respectively, whereas Section 6 addresses all *in situ* treatment options since subsurface treatment does not usually distinguish between the media that are involved in a site remediation. Lastly, Section 7 provides some additional observations and remarks regarding MGP site remediation and the application of remediation technologies at these sites given their typical locations and contemporary settings.

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SCOPE AND LIMITATIONS OF REPORT

The purpose of this report is to provide a source of information for utility representatives who are conducting an initial identification and assessment of remediation strategies for the management of an MGP site. The remediation technologies that are presented represent a set of *ex situ* and *in situ* management techniques which can be incorporated into a site-wide management strategy to address most, if not all, MGP sites. These technologies were selected based upon their commercial availability and/or their previous application to MGP sites or sites with related contamination. For this reason, several evolving remediation techniques have not been included in this report because they are in the early stages of development or have not been applied to MGP sites. Furthermore, the report focuses on the treatment of source material and/or contaminated media (i.e., groundwater, soil, and sediment) and does not specifically address contaminated structures and equipment or debris and fill. Nevertheless, many of the management techniques that are discussed can be applied to these materials and, where appropriate, these applications have been identified.

It should not be inferred that the preparation of this report is a recognition that remediation will be required at all, or parts of all, MGP sites. Nor should it be inferred that if remediation is required, all of the remediation technologies that are described in this report will be required at a site or that other remedial technologies may not also be appropriate in some instances. Rather, it should be understood that each individual site must be evaluated to determine site-specific environmental conditions. These conditions will establish the basis to determine if remediation is necessary and, if so, to what degree treatment is required.

2.1 NATURE AND EXTENT OF INFORMATION

2.1.1 TECHNICAL/COST DATA

The technical information in this report is provided in two different formats. First, there are detailed technology descriptions which have been provided in Appendix A. These descriptions include the following types of information: (1) description of the technology, (2) a listing of the applicable waste matrix and chemicals with some indication of those chemicals that are the primary focus of the treatment, (3) a summary of the primary technical considerations associated with the use of the technology, (4) the status of the technology applications, especially with MGP site residuals, and (5) the identification of key references which provide both performance and cost information for the technology applications. The technology descriptions provide a quick reference for understanding each technology and its potential applications to contaminated matrices at MGP sites. These descriptions were obtained from a set of references that were produced by the Niagara Mohawk Power Corporation (Remediation Technologies, Inc., 1993), the Gas Research Institute (Gas Research Institute, 1987), and the Electric Power Research Institute (Electric Power Research Institute, 1991).

Technology information is also presented within the text of the report. These discussions also describe the technology operation but place more emphasis on the critical factors which can influence its selection or performance. In addition, specific applications of the technology to MGP site residuals are noted and discussed to highlight previous experiences within the utility industry. These experiences have been documented in more detail in Appendix B. This appendix presents brief summaries of remedial actions that have been implemented by utilities at MGP sites. The information that is reported was gathered through a targeted phone survey of utilities that have been actively pursuing remediation at MGP sites in the recent past.

It should be emphasized that the technical information provided in this report is not meant to replace a detailed analysis of each site-specific technology application. On the contrary, the final selection of a remediation strategy for any MGP site that requires some remedial action should be done only after a detailed review of the 'site characteristics and the capabilities of the specific remediation technologies are completed. Furthermore, it should be noted that only limited cost information and performance data for each remediation technology have been provided and that these data were extracted from specific references in the general literature. This selected presentation of cost and performance data was a deliberate attempt to encourage the reader to retrieve the data from the cited references and to thoroughly examine it before using it for a specific site application. On the other hand, this report does provide the reader with the information necessary to initiate the identification and evaluation of remediation technologies for use at MGP sites. On the basis of these evaluations, integrated site remediation strategies can be developed using combinations of *ex situ* and *in situ* treatment options for source material and contaminated media. These strategies will form the basis for feasibility study analyses and more detailed performance and economic assessments.

The importance of the cost information in the evaluation of remediation strategies warrants an additional caution regarding its use. The most common cost data are available from either vendors of the remediation technologies or from the general literature where the results of generic or site-specific economic case studies have been reported. While these data are informative and provide a broad perspective on potential site remediation costs, there is a great deal of uncertainty associated with the application of these data to any specific site. This uncertainty arises from two facts. First, the vendor information typically focuses only on the cost for the treatment of a specific contaminated media (e.g., soil or water) from the point of entry into the treatment process to the point of exit. No consideration is usually given to the cost associated with the removal and preparation of the contaminated media prior to treatment, the management of secondary environmental impacts during treatment, the interactions between the management strategies for different media, or the final disposition of the treated materials. As such, this unit treatment cost significantly underestimates the actual cost of "cradle-to-grave" management of the media. Second, the generic economic evaluations and case study results, while including many of the costs in addition to treatment, cannot adequately reflect the site-specific conditions at any given site and their impact on the cost. For example, these evaluations may include the cost for the separation of debris from soil prior to the treatment of the latter in a thermal desorption unit; however, the location, volume, and nature of the soil/debris mixture is site-specific and must be evaluated on a site-by-site basis. In spite of these limitations, the available information does provide a checklist of the cost items that should be considered as part of a site remediation and order-of-magnitude cost estimates for some of these items. This information can be used, with caution, as an initial step in the estimation of the cost for a site-wide remediation strategy.

2.1.2 VENDORS

Specific vendor information has not been provided in this report for a number of reasons. First, it is not possible to present a comprehensive list of all vendors who provide a specific technology. As such, there was a concern that some vendors might be inadvertently omitted from this report. Second, there was a concern that the inclusion of a vendor list in this report would be interpreted as a confirmation of the capabilities or experience of the individual vendors. Since a technical review of technology vendors was not within the scope of this study, this interpretation would be inappropriate. Third, it was understood that a vendor list would be quickly outdated since new vendors enter and existing vendors exit from the marketplace on a routine basis. For these reasons, it has been left to each utility to assemble its own information based on the available remediation vendors and to conduct its own evaluations of their capabilities based upon the remediation needs of each MGP site.

2.1.3 REGULATORY APPROVAL AND ACCEPTANCE

The regulatory acceptance and approval of a remedial technology may be the overriding issue that will determine its use at a specific site. The technical staff of the governing regulatory agency, be it the Federal EPA or the State environmental agency, must have confidence that the selected remedial technology has the capability to accomplish the goals of the site remediation. Without this confidence, they will be reluctant to accept a technology as part of a site remediation because they will ultimately have to defend that selection to other regulatory bodies or the public-at-large. Furthermore, even if technical acceptance is provided, the technology must be capable of meeting the necessary regulatory requirements to permit its use as part of a site remediation. These requirements can include, among other things, such items as air emission and water discharge limits for site-specific permits, noise and odor constraints associated with local ordinances, or other site-specific applicable or relevant and appropriate requirements (ARARs). Since regulatory acceptance and approval are so site-specific, they are not extensively analyzed in this report. Nevertheless, it is important to realize that these factors may ultimately be the ones that govern which remedial technologies are used at a site.

2.2 MULTI-MEDIA CONSIDERATIONS

It is recognized that there are multi-media considerations when a remediation technology is utilized for the treatment of a specific media, e.g., treatment of contaminated soil can generate contaminated water which must be properly managed. These considerations can require the use of additional treatment technologies and, hence, increase the cost of the remediation effort. It is also true that certain economic efficiencies can be realized if the multiple remediation efforts are properly integrated. For example, it may be possible to minimize the cost of contaminated water management at a site if the groundwater treatment system can be designed to permit the treatment of aqueous streams that are generated during soil treatment. These cross links have not been specifically addressed in this report although in certain instances they have been highlighted due to their specific importance relative to the performance or cost of a remediation technology application. Nevertheless, most of the secondary offgases, wastewaters, and solid or sludge residues that may be produced during a site remediation can be managed using the remediation technologies that are presented in this report.

2.3 UPDATING AND TRANSFER OF TECHNOLOGY DATABASE

The information that is provided in this report will be updated, as needed, to provide the utility industry with the most current summary of potential remediation technologies for MGP sites. For this reason, the information has been provided in a three-ring notebook so it can be readily replaced with new information as it becomes available. To make the updated information even more readily available, future consideration will be given to the incorporation of the information in this report into an electronic data base.

3

GENERALIZED REMEDIATION STRATEGIES FOR MGP SITES

Remedial actions at MGP sites typically focus on source material and contaminated media such as soil, sediment, and groundwater. The generalized remediation strategies that are designed to address these materials can be comprised of either *in situ* or *ex situ* management techniques as shown in Figure 3-1. The advantage of *in situ* management is that it often eliminates the need for the removal of the source material and contaminated media as well as the final disposition of the treated materials. This advantage is negated by the fact that *in situ* treatment (in contrast to containment) is not as well developed as most *ex situ* treatment approaches and it is more difficult to implement and to monitor its success. For this reason, *ex situ* treatment and *in situ* containment strategies have dominated most MGP site remediation efforts to date and are the focus of this report. Nevertheless, *in situ* treatment options, even though they are emerging and developing, may still play a role in MGP site management and are discussed in this report.

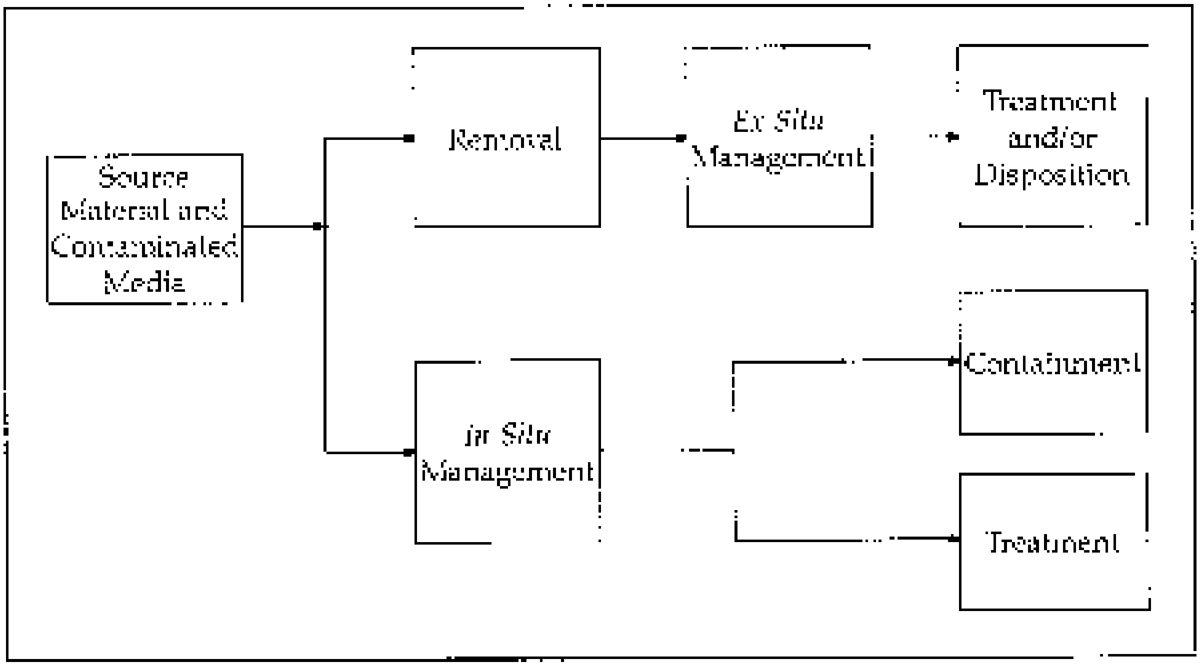

Figure 3-1. Generalized Remediation Strategies for Source Material and Contaminated Media at MGP Sites.

The most critical factors which influence the development of *ex situ* and *in situ* remediation strategies for MGP sites include the nature and extent of the contamination and the location of the contamination relative to the ground surface and existing site structures.

3.1 EXTENT OF CONTAMINATION

It is common to find concentrated areas of the two primary source materials, i.e., tars and purifier box wastes, at an MGP site, The tars were often left in the subsurface portions of the gas manufacturing process equipment during demolition and the spent purifier box wastes were commonly used as fill throughout the site. Targeted removal of these materials may be justified when they are easy to identify, are easily accessible and are leaching contaminants to the surrounding sod or ground water. However, excavation is not always necessary or possible. In these instances *in situ* containment may be an effective alternative strategy. These techniques usually require the presence of a subsurface, geologic confining layer within a reasonable distance from the ground surface. Even where the *in situ* treatment of these materials may not be effective (such as in the cases of elevated contaminant concentrations) *in situ* stabilization may be appropriate. This technique is designed to stop the migration of contaminants by chemically immobilizing them.

Many of the sites also may have contamination consisting of source materials that are mixed with other MGP site residuals, such as ash, or with surrounding soil or debris. This contamination is more dilute than the source materials, themselves, and is often spread randomly throughout the site. This random pattern of deposition reflects some of the common practices of the gas manufacturing industry such as the use of mixtures of ash and other process residuals as onsite fill as well as the occurrence of accidental spills and leaks. Large areas of dilute contamination makes *ex situ* management difficult due to the large volumes of contaminated media that are involved and the impact of these volumes on materials' removal, handling, and treatment practices. Practicable alternatives and approaches to the remediation of this contamination, if it is necessary at all, include *in situ* containment and *in situ* treatment options. The latter are attractive in this circumstance since contaminant concentrations are generally more dilute and are amenable to *in situ* treatment techniques.

3.2 NATURE OF CONTAMINATION

The nature of contamination at an MGP site reflects the characteristics of the source materials and generally includes organic chemicals such as VOCs, PAHs, and phenolics and inorganic chemicals such as ammonia, cyanide, sulfide, or selected metals. The remedial technologies which may be used for the management of this contamination are dictated by which group of chemicals, i.e., organic or inorganic, is · the cause for concern at the site. For example, the inorganic contaminants are typically more amenable to fixation while their organic counterparts are more responsive to biological treatment. At MGP sites, organic contaminants such as VOCs and PAHs tend to be the primary targets of remediation although cyanide has also been an issue where extensive onsite management of the purifier box wastes occurred.

3.2.1 FREE-PHASE HYDROCARBONS

The most common free-phase hydrocarbon that is present at an MGP site is tar (i.e., coal tar, carburetted water gas tar, or oil tar). Since the majority of these tars have a specific gravity greater than 1, they are also called DNAPLs or dense non-aqueous phase liquids*. DNAPLs may occur as "free phase" or "residual" contamination. The flee-phase DNAPL is an immiscible liquid that is capable of migrating vertically or laterally through a geologic zone. Where vertically migrating DNAPL encounters a geologic formation of relatively low permeability, an accumulation or "pool" may form. On the other hand, residual DNAPL is an immiscible liquid that is held within the soil or rock by capillary forces. This DNAPL is generally not capable of migrating or being displaced by normal groundwater flow. Both free-phase and residual DNAPL can slowly dissolve in groundwater and produce "plumes" of aqueous contamination or volatilize to yield contaminated subsurface vapors.

Most DNAPLs at 'MGP sites have entered the subsurface environment by escaping from subgrade structures such as gas holder tanks, tar separators or tar wells or by direct placement of the free-phase DNAPLs on the ground. Hence, it is common to have a column of soil with residual DNAPL beneath these structures down to the confining layer. This column of soil can extend through the vadose zone and into the saturated zone depending upon the geologic features of the site. A pool of free-phase DNAPL may be present at the confining layer and, depending upon the contour of this layer, lateral migration of the DNAPL may have occurred.

In some instances, the vertical migration, and hence, vertical distribution of DNAPLs may be quite complicated. For example, lenses of geologic material of reduced permeability (e.g., clay) can interrupt the downward vertical migration of the DNAPL and result in perched pools of DNAPL and/or the lateral migration of the DNAPL before it reaches the depth of the confining layer. Conversely, the confining layer may be discontinuous or contain fractures which permit the downward vertical migration of the DNAPL to depths below the confining layer. This continued vertical migration

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* LNAPLs, or light non-aqueous phase liquids, are free-phase hydrocarbons with a specific gravity of less than 1. These hydrocarbons may also be present at MGP sites although they are more frequently associated with sites that have been contaminated with crude oil or petroleum products such as gasoline or fuel oils. For this reason, LNAPLs have not been identified in this report as a specific media for remediation at an MGP site.

through fractures can often include a lateral component since the fractures generally occur along bedrock planes which are not necessarily oriented perpendicular to the ground. This results in the presence of DNAPL, at depth, beneath otherwise uncontaminated areas of the site.

3.2.2 PURIFIER BOX WASTES

Purifier box wastes were often used as fill throughout the site. They may have been mixed with ash, clinkers, and even flee-phase hydrocarbons prior to their use. As such, it is common to find purifier box wastes spread non-uniformly across a site, both above and below the water table. At some sites, if onsite fill was not required, the purifier wastes may have been sold or disposed of offsite and may not be present on the site.

3.2.3 GROUNDWATER

The low molecular weight compounds that are present in the DNAPL (e.g., benzene, toluene, xylenes, or naphthalene) are the most soluble in water and normally dominate groundwater contamination at an MGP site. The concentrations of these contaminants in the groundwater are controlled not only by their solubilities in water but also by their concentrations in the DNAPL and the extent of contact that occurs between the flee-phase/residual DNAPL and the infiltrating surface water and flowing groundwater. These contaminants are not appreciably attenuated by subsurface soils and therefore migrate the farthest distances from the DNAPL zones in both the vertical and horizontal directions. Since the sources of groundwater contaminants have often been in contact with the groundwater for anywhere from 30 to 100 years, it is likely that the release and migration of the contaminants in the subsurface have achieved steady-state conditions. For this reason, contaminant concentrations in the groundwater may not vary with time in the immediate zone of influence of the DNAPL. However, one of the greatest challenges in the management of contaminated groundwaters at an MGP site is to predict the contaminant concentrations that will be present in the subsurface over the course of a long-term remedial action that involves groundwater containment, recovery and treatment.

Groundwater remediation at MGP sites can be complicated by the presence of DNAPLs in the subsurface. It is well recognized now that the DNAPLs represent a continual source of contamination to the groundwater and have the potential to greatly extend the time that is required for its remediation. As such, removal of the DNAPLs, if possible, may be desirable in these instances and may be the only option that will lead to a cost effective restoration of the groundwater. At the same time, the U.S. EPA has issued a directive to provide guidance for the evaluation of the groundwater restoration.[*] This guidance reflects the experience in the United States over the past decade which indicates that the achievement of final groundwater clean-up standards may not be practicable at some sites due to the limitations of remediation technology. Specifically, the EPA identified groundwater restoration in the presence of DNAPLs as "one of the most difficult technical challenges" and they cite the prevalence and intractability of DNAPL contamination as one of the principal reasons for the development of the guidance. The guidance specifies the procedures required to determine whether groundwater clean-up goals are technically achievable at a particular site and how to establish an alternative, protective clean-up strategy where restoration is determined to be technically impracticable.

3.2.4 SOIL AND SEDIMENT

Unlike groundwater, the presence of contaminants in the solid matrices (i.e., soil and sediment) are much more heterogeneous and their areal and vertical distribution are much less predictable. This fact tends to shift the selection of remedial technologies to single technologies that are capable of dealing with a wide range of contaminant concentrations rather than to the selection of multiple technologies that are each targeted for individual classes of contaminants and that are assembled into an integrated treatment train. As a result, the technology selections are based upon the contaminants that are the most difficult to treat in the contaminated matrix. For example, if there is a potential for the presence of both VOCs and PAHs in a contaminated soil, thermal treatment might be selected over soil aeration since the former is capable of treating both classes of contaminants whereas the latter only treats the VOCs. Similarly, if contamination is attributed to both organic and inorganic chemicals or metals, stabilization may be selected in lieu of thermal treatment to effect a more comprehensive treatment of the contaminated matrix.

3.3 LOCATION OF CONTAMINATION

Remediation strategies for the source materials and the contaminated soil and sediment are also influenced by the location of the contamination. The presence of the contamination in the near-surface, above the groundwater table, and clear of any site structures tends to favor the removal and *ex situ* treatment of the materials. The presence of the contamination below the groundwater table does not exclude its removal, but it does introduce a complicating factor with regards to the structural

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[*] *Guidance for Evaluating the Technical Impracticability of GroundWater Restoration,* Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Directive 9234.2-25, September, 1993.

support required to complete the excavation and the management of the water removed during the excavation. On the other hand, if the contamination is under an existing structure or at a significant depth below the ground surface, removal may be impossible and *in situ* management options may be the only means to address the contamination problem. A similar statement can be made for groundwater restoration even though the techniques for its interception, containment, and or recovery are generally capable of addressing most circumstances at MGP sites. As the depth of groundwater contamination increases, management options become more limited (e.g., physical barriers may no longer be a viable option) and the confidence that these options will be effective decreases with the increasing uncertainty about the specifics of the subsurface geology and hydrogeology.

4

EX SITU TREATMENT OF CONTAMINATED WATER

4.1 CONCEPTUAL REMEDIATION STRATEGY

Figure 4-1 provides a conceptual remediation strategy that depicts the sequence of unit operations that are typically required to permit the discharge of contaminated water from MGP sites into a surface water body, a POTW (publicly owned treatment works), or the subsurface. The first treatment step addresses the primary removal of any insoluble materials which can include solid matter as well as flee-phase hydrocarbons. The removal of these materials is driven by both operational as well as environmental considerations. For example, the insoluble material has the potential to inhibit treatment in downstream unit operations by plugging pipes and equipment. In addition, both suspended solid matter and flee-phase hydrocarbons are often regulated in the form of effluent discharge limits on total/fixed suspended solids and oil and grease, respectively. Finally, the free-phase hydrocarbons also serve as a source of dissolved VOCs and PAHs which are also the subject of typical effluent discharge limitations.

The next treatment step in Figure 4-1 recognizes that an additional level of treatment (i.e., secondary treatment) may be required to remove insoluble materials such as suspensions of fine particulates or colloids of hydrocarbon and water. This treatment often requires the addition of chemical additives and/or heat to enhance coagulation and flocculation or to separate hydrocarbon/water emulsions. During these treatments, reductions in the following contaminants can be achieved: (1) total suspended and fixed solids, (2) metals, (3) oil and grease, (4) total organic carbon, and (5) selected VOCs and PAHs. The extent of removal of VOCs and PAHs varies depending upon the actual processes that are used to accomplish the treatment. For example, since the five- and six-ring PAHs are primarily associated with finely suspended particulate or hydrocarbon/water colloids, a reduction in their concentrations will be achieved as these materials are removed.

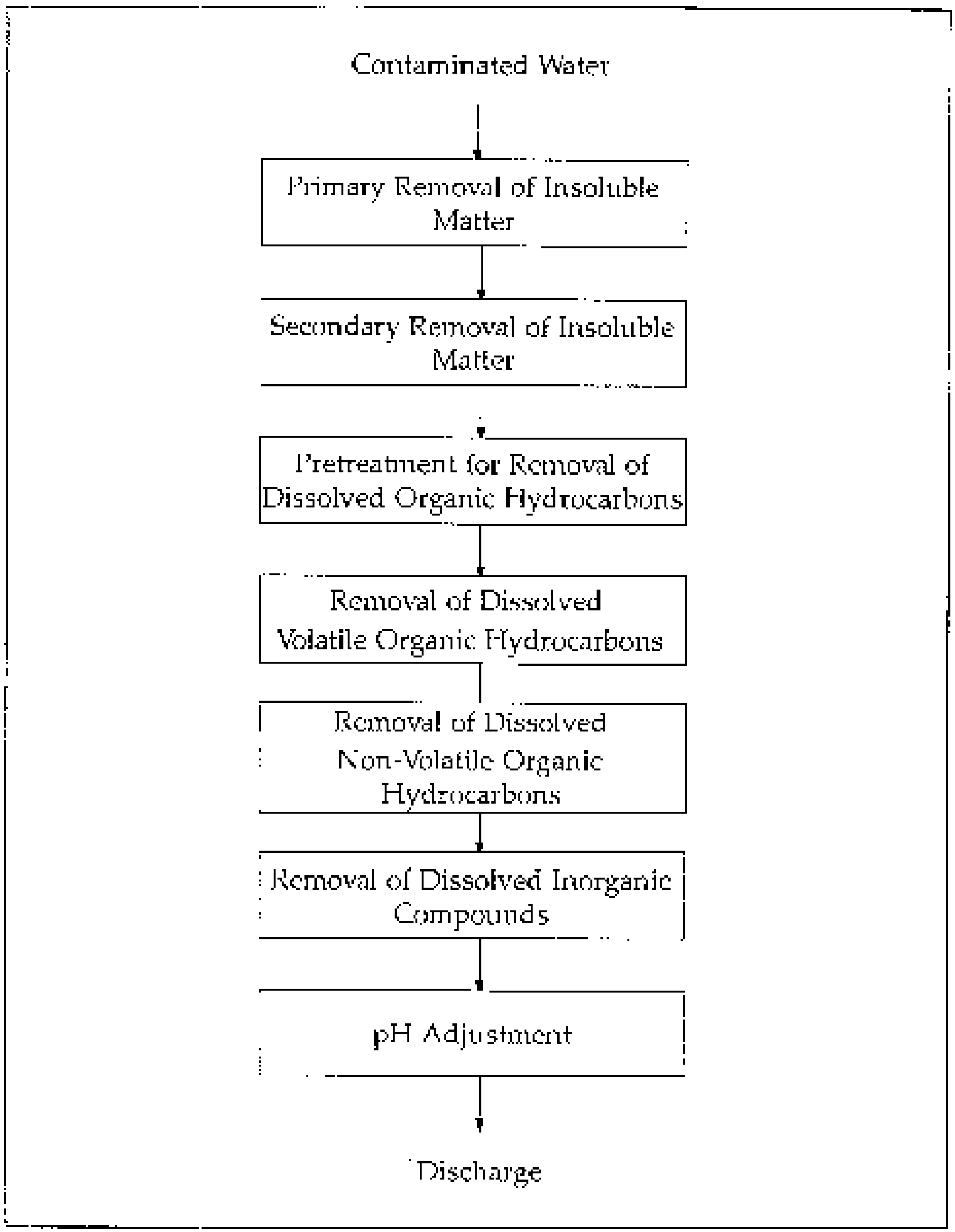

Contaminated Water
Primary Removal of Insoluble Matter
Secondary Removal of Insoluble Matter
Pretreatment for Removal of Dissolved Organic Hydrocarbons
Removal of Dissolved Volatile Organic Hydrocarbons
Removal of Dissolved Non-Volatile Organic Hydrocarbons
Removal of Dissolved Inorganic Compounds
pH Adjustment
Discharge

Figure 4-1. Conceptual remediation Strategy for the Management of Contaminated Water From MGP Sites.

The removal of dissolved organics is the focus of the next three treatment steps, the first of these providing pretreatment and the latter two targeting the treatment of dissolved volatile and non-volatile organic hydrocarbons, respectively. Pretreatment consists of the precipitation and removal of dissolved metals such as iron and manganese to prevent their interference during the treatment of the dissolved organic contaminants. If these metals are not removed under controlled oxidizing conditions, they have the potential to oxidize and precipitate during the downstream treatment of the water which can result in the fouling of the process equipment and the poor removal of the organic contaminants. Following this pretreatment step, the removal of VOCs, such as benzene, is generally achieved using air or steam stripping. Lastly, carbon adsorption, biological oxidation, or chemical oxidation are used for the non-volatile organic compounds. The treatment of the VOCs separate from the non-volatile organic compounds provides some flexibility in the treatment scheme which has the potential to reduce the overall cost of treatment. For example, while the VOCs can often be removed using the same treatment processes that address the non-volatile contaminants, it may be possible to remove them more cheaply by using an upstream process that is designed explicitly for their removal, i.e., strippers. These technical and economic tradeoffs must be examined in each case to determine the optimal mix of treatment technologies for achieving the treatment goals.

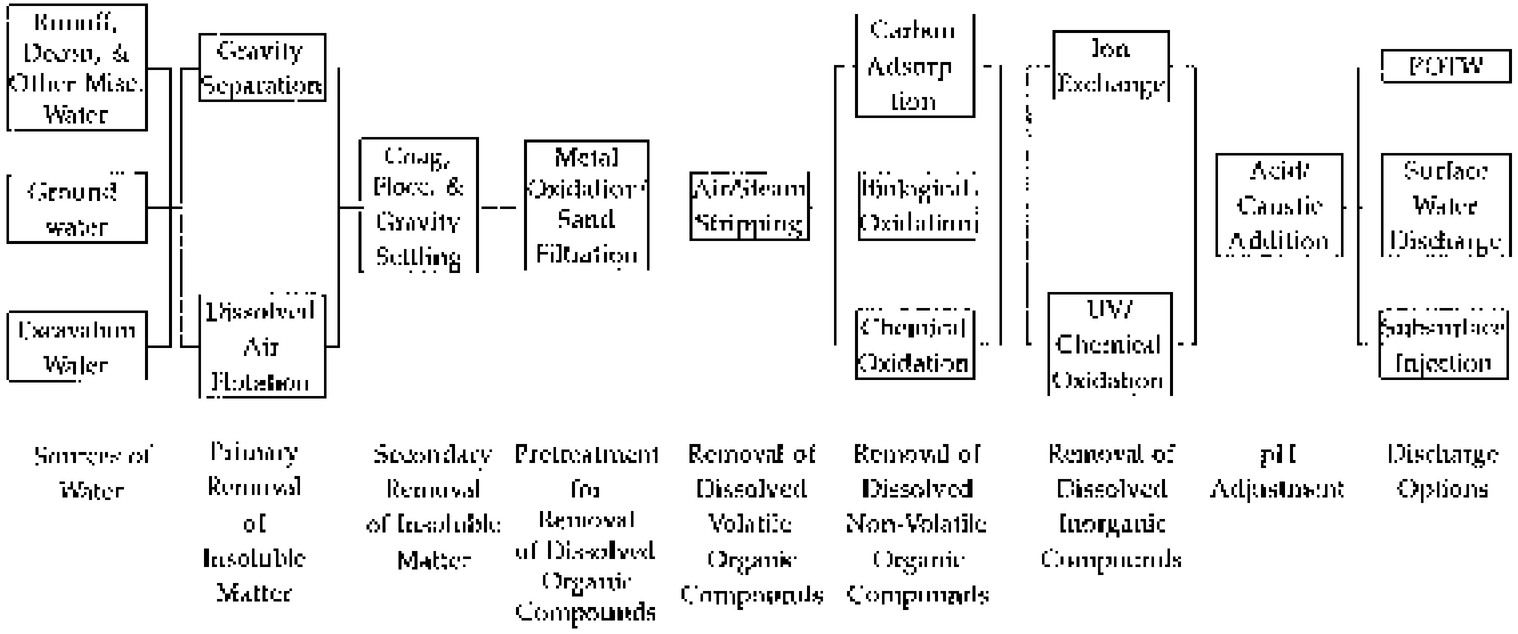
There may be soluble inorganic contaminants that remain in the water following the treatment of the dissolved organic constituents. Of particular note in this category is total cyanide since its removal in other unit operations, with the exception of chemical oxidation (with ultraviolet or UV light), is not anticipated. As such, the independent removal of cyanide can be achieved using either ion exchange resins or UV/chemical oxidation processes. However, it should be noted that if oxidation processes are used for the treatment of dissolved organics, there may be no need for a separate treatment step for cyanide.

The last step before final discharge generally involves a final adjustment of the pH of the water. The adjustment of the pH may be up or down depending upon the nature of the upstream process steps. For example, if an exchange resin is used for the removal of the cyanide, it may result in an increase in the pH and the addition of acid may be required to return the water to a neutral pH to meet the effluent discharge limits.

4.2 IDENTIFICATION AND EVALUATION OF INTEGRATED REMEDIATION STRATEGIES

Figure 4-2 presents the overall framework for the selection of individual remedial technology options for the management of contaminated water at MGP sites. For each of the major contaminant removal steps described in Figure 4-1, a candidate treatment technology or list of technologies has been identified. For the most part, these technologies have been incorporated into Figure 4-2 because they represent unit operations that have been field tested at MGP or other related industrial sites. The development of an integrated remediation strategy may require the selection of individual technologies for each removal step to achieve compliance with the effluent discharge limitations. Alternatively, technologies may only be required for one or two removal steps, depending upon the quality of the influent water and the desired quality of the treated effluent. A brief description of each individual technology that is listed in Figure 4-2 is provided in Appendix A of this document.

There are numerous integrated remediation strategies that can be developed from Figure 4-2 for the treatment of contaminated water from MGP sites. The development of these strategies depends upon a number of considerations including influent and effluent water quality, capability of treatment technologies, and cost. The more complex treatment strategies result when it is assumed that the removal of all classes of contaminants will be required (i.e., insoluble materials, dissolved organic compounds [both volatile and non-volatile], and dissolved inorganic compounds). Should this not be the case, it is possible to eliminate some of the treatment combinations and to reduce the remediation strategy to only one or two treatment steps. The remainder of this section discusses each treatment technology that is presented 'in Figure 4-2 and presents the rationale for its incorporation into an integrated remediation strategy as well as the advantages and disadvantages of its application to contaminated water from MGP sites.



NOTE: The order of the treatment technologies that is shown generally reflects the sequence that is required to achieve the most effective treatment. However, alternative sequences may be appropriate based upon the influent water quality and the site-specific discharge requirements.

Figure 4-2. Technology Selection Framework for Management of Contaminated Water at an MGP Site.

4.2.1 REMOVAL OF INSOLUBLE MATERIALS

Gravity Separation/Dissolved Air Flotation

Figure 4-3 presents a process flowsheet for a gravity separator. The separator provides the residence time and flow patterns that are necessary to effect the removal from water of free-phase hydrocarbons or other insoluble materials that float on water as well as settleable solids or free-phase hydrocarbons that sink. The floating materials are skimmed or pumped from the surface and the settleable materials are drained or scraped from the bottom of the separator. Gravity separators are rarely used alone for water treatment unless their discharge is directed to a POTW. In that case, the gross separation of the insoluble materials may satisfy the pretreatment requirements of the POTW. For most other discharge options, the removal of contaminants that are not addressed by gravity separation, such as dissolved inorganic or organic contaminants, is often required and dictates the need for other treatment unit operations.

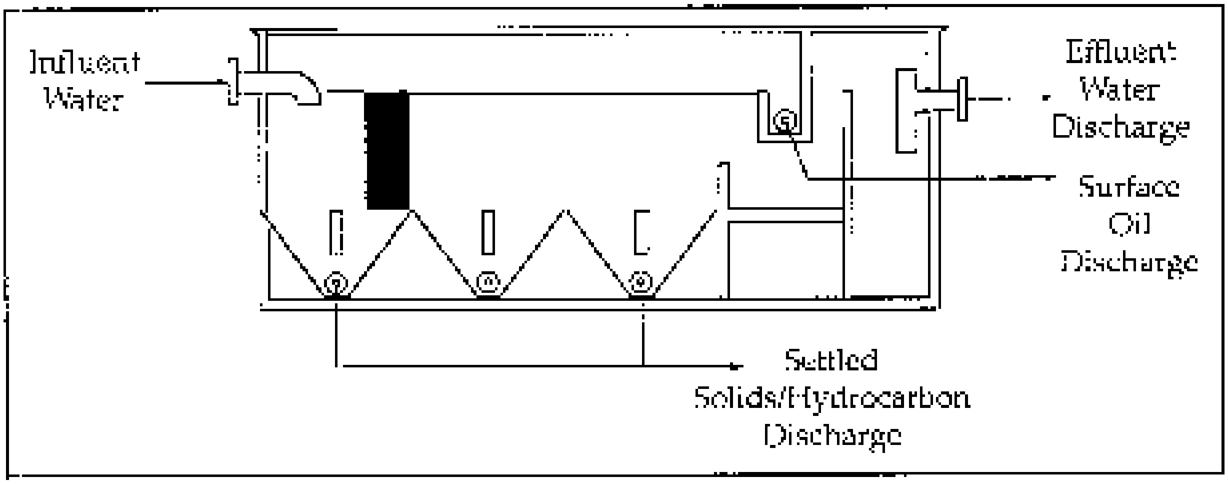


Figure 4-3. Process Flowsheet for Gravity Separator.

Gravity separators are capable of removing those insoluble materials. that have a density that is significantly different than that of water. The greater the density difference, the more effective is the separation and the more easily it can be achieved. For example, in some instances, if the density differences are sufficiently large, it is likely that the separation can be accomplished by simply providing a storage tank with a sufficiently long residence time to permit the settling of the insoluble material. However, the presence of a hydrocarbon/water emulsion with a density near that of water can pose a difficult problem for this treatment unit. Typically, when these emulsions are present, the addition of chemicals and/or the application of heat are required to break or remove the emulsion. Chemical addition can occur upstream of the separator or immediately downstream of it. This choice is dictated by the overall quality of the water, with the more contaminated waters requiring gross separation prior to the addition of any chemicals.

Dissolved air flotation (DAF) is generally applied to contaminated water where the specific gravity of the suspended material is very close to that of water. As such, these materials settle very slowly or not at all and it is much easier to remove them using air flotation. The DAF process operates by dissolving air under pressure into the influent water (pressure flotation). Upon release of the pressure, the dissolved air forms a fine suspension of bubbles which float insoluble matter to the surface where it is removed by a skimming mechanism. The suspension of bubbles can also be produced by decreasing the pressure in the flotation unit through the application of a vacuum. While under vacuum, the air that is naturally dissolved in the influent water is released. The use of vacuum systems is less common than the pressurized systems. A process flowsheet of a pressurized DAF process with an effluent recycle is shown in Figure 4-4. In this figure, a portion of the clarified water effluent is recycled to the flotation unit after it has been pressurized and combined with compressed air. The escaping air bubbles from this stream attach to the insoluble material that is present in the influent water which causes it to rise to the surface. The surface skimmer removes this material while the heavier materials sink to the bottom of the unit and are removed by the bottom sludge collector. A DAF unit has been incorporated into a groundwater treatment system at an MGP site in Maryland. This unit was chosen to supplement gravity separation when it became evident that the specific gravity of the insoluble hydrocarbons in the water were not substantially different than that of water and a good gravity separation of the hydrocarbons from the water could not be achieved. This circumstance may be more common at sites which were predominated by the carburetted water gas process than by the coal gas process since the specific gravity of carburetted water gas tars is known to be very close to that of water and their formation of emulsions with water was not an unusual occurrence during plant operation.

The cost of gravity separation and dissolved air flotation is not large and is dominated by the primary separation vessels. Major operating costs can be associated with the disposal of the flee-phase hydrocarbons that are collected from the water. As such, since most downstream treatment technologies would require the removal of insoluble materials prior to accepting the water, it is almost imperative that these units be included in any water treatment system that is designed for the management of contaminated water from MGP sites. This is especially true since this relatively inexpensive treatment step can provide protection for the more expensive downstream treatment options.

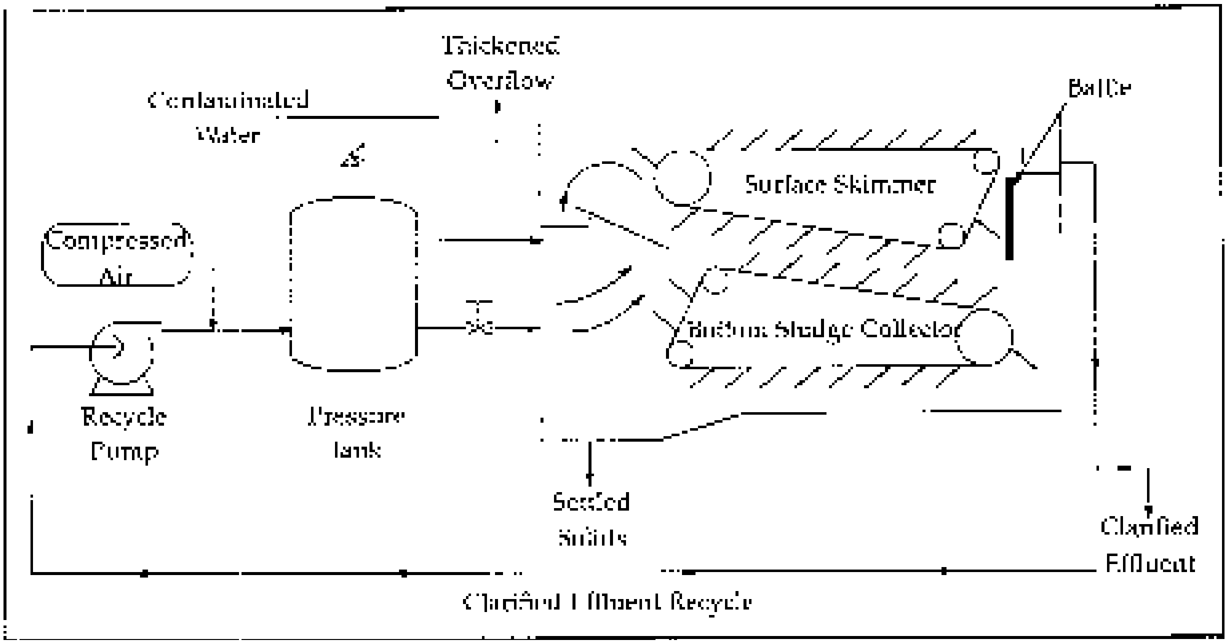


Figure 4-4. Process Flowsheet for Dissolved Air Flotation Unit.

Gravity Separation Followed By Coagulation and Flocculation

Chemical coagulation and flocculation is a conventional water treatment technology that has been tested at the bench and field scale on contaminated water from MGP sites. It provides an additional level of treatment for insoluble materials beyond gravity separation and dissolved air flotation alone, and is effective in removing or reducing particulates, as well as suspended and/or insoluble organic compounds from water. The process requires the addition of chemical additives such as cationic organic polymers, alum, and ferric chloride. In the coagulation step, coagulants are added which decrease the repelling forces between suspended particles and cause them to aggregate. During flocculation, slow mixing causes the destabilized particles to collide and form fluffy, gelatinous particles or flocs. When the flocs become more dense than water, they settle and can be removed by conventional gravity separation. As the flocs settle, they capture very small or colloidal size particles that are otherwise difficult, if not impossible, to remove. Chemical coagulation and flocculation do not remove dissolved contaminants. A typical process flowsheet for this treatment of contaminated water is shown in Figure 4-5. The major equipment in Figure 4-5 includes mix tanks, chemical feed systems, pumps, and a gravity separator. It is not uncommon for a gross separation step, which also utilizes a gravity separator (or dissolved air flotation unit), to precede this treatment since it can reduce the quantity and cost of chemical addition that is required to achieve the desired separation. It should also be noted that the process flowsheet includes the addition of both cationic and anionic polymers to aid the coagulation/flocculation process. The use of both of these chemicals may not be necessary and should be evaluated during the design stage through using simple laboratory jar tests.

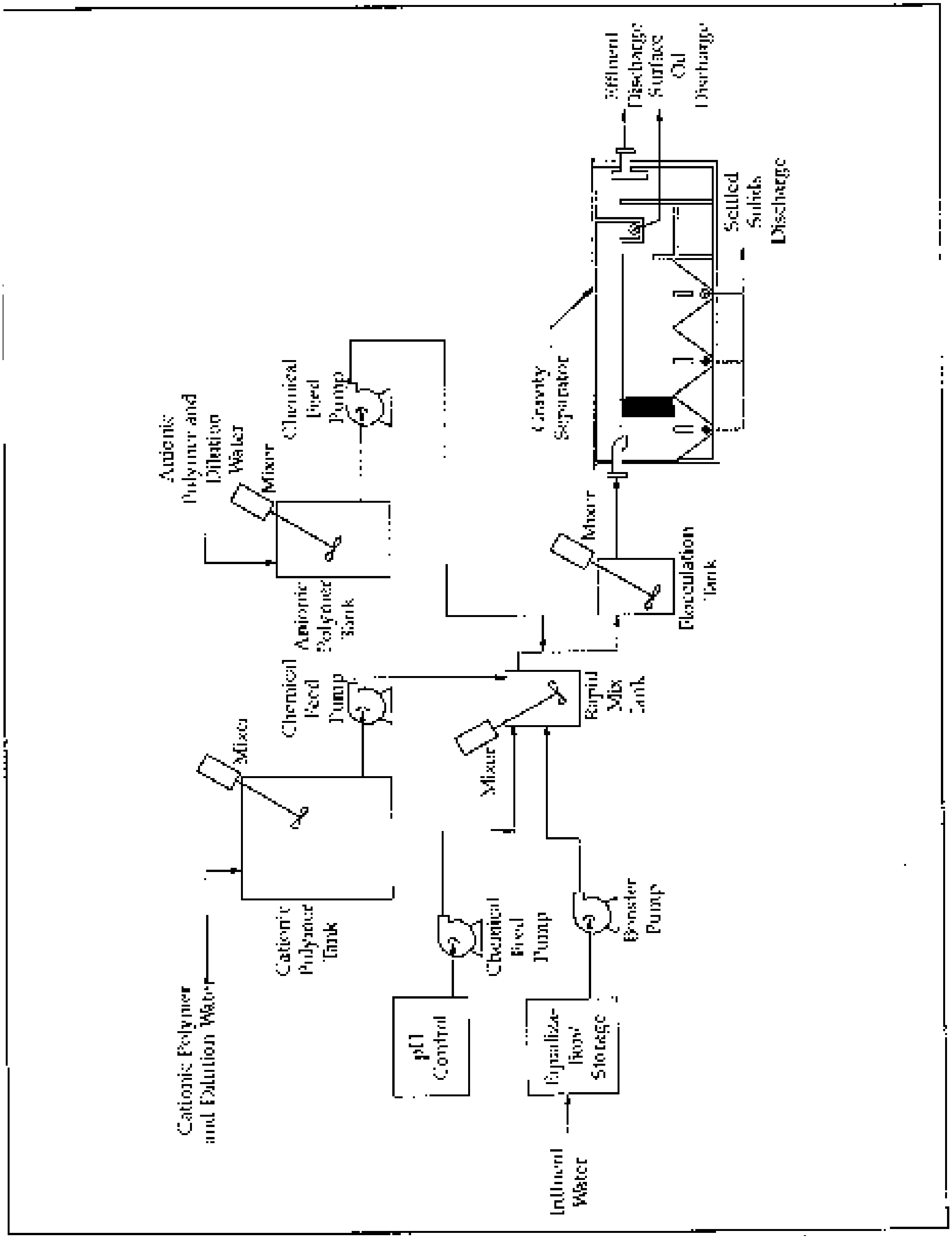


Figure 4-5. Process Flowsheet for Chemical Coagulation and Flocculation.

Some hydrocarbon/water emulsions .can be quite stable and very difficult to destabilize. As such, other chemical additives such as acid or caustic as well as the application of heat may be required to effect their removal from the water. Fine particulate can also act in a manner similar to a hydrocarbon/water emulsion in that they will not readily separate from the water phase. The presence of these materials may also increase the quantity of chemicals that are required and/or require the addition of other chemicals in addition to those mentioned above. While hydrocarbon/water emulsions have not been observed extensively at MGP sites during remediation, the historical literature does discuss, at length, their presence during the manufacture of carburetted water gas. (These emulsions were a rarity in coal gas plants). Given this history, it is anticipated that hydrocarbon/water mixtures from the subsurface of a carburetted water gas plant site may be more prone to form these emulsions than those from a coal gas plant site.

It is interesting to note that the fine particulate and colloidal hydrocarbons that are removed during chemical coagulation and flocculation may also be the primary contributors of 5- and 6-ring PAHs to the water phase. This occurs since the 5- and 6-ring PAHs are very insoluble in water and are retained on the surfaces of the solids or within the hydrocarbon colloids that are present in the water. Since these materials cannot be separated from the water phase, they are analyzed as part of it, thereby contributing 5- and 6-ring PAHs to the water analysis. The primary indication of this occurrence is the presence of 5- and 6-ring PAHs in the water phase at concentrations above their solubility limits. Accordingly, the ability to achieve effluent discharge limits for the heavier PAHs may require the separation of the major portion of these suspensions of fine material from the water phase.

Similar to gravity separation or dissolved air flotation, it is likely that chemical coagulation and flocculation will be required at most MGP sites. Since there is always the potential for the presence of fine suspended solids and hydrocarbon colloids in the water phase and since it is known that these materials have the potential to interfere with the effectiveness of downstream treatment technologies, the use of chemical coagulation and flocculation would serve as a precaution to ensure that cost-effective treatment of the water is achieved. At the same time, the greatest cost for the application of this treatment option is associated with the use of the chemical additives which increases with the concentration of the contaminants. Consequently, it is often cost-effective to subject the water to gravity separation or dissolved air flotation prior to treatment to reduce the chemical requirements even though it includes a gravity separator for the final separation of the floc from the water. The other significant operating cost associated with this treatment option is the cost of managing the solids that are recovered from the treatment. For this reason, it is imperative that an optimal dose of chemical additives be determined and utilized.

4.2.2 REMOVAL OF SOLUBLE ORGANIC CONTAMINANTS

Pretreatment (Metal Oxidation Followed by Sand Filtration)

The removal of selected dissolved metals may be required following the removal of the insoluble matter. Typically, this treatment step is necessary to meet concentration limits associated with the influent streams of the downstream treatment technologies for soluble organic contaminants. Alternatively, there may also be effluent discharge limits which must be met for the dissolved metals themselves. The identical treatment technologies can be used in both instances; however, their location within the overall treatment train may be different.

Metals removal can be accomplished using chemical precipitation. If necessary, phosphate, sulfate, and fluoride can also be removed in this manner. The process involves either oxidation or reduction reactions that produce insoluble precipitates which can be easily removed by filtration or sedimentation. Permanganate oxidation is a special case of chemical oxidation where potassium permanganate ($KMnO_4$) is added to an influent water for the purpose of oxidizing and precipitating iron and manganese. If this removal is not conducted in a controlled manner, the insoluble precipitates may form during the aeration of the influent water that occurs during other processing steps, e.g., air stripping or carbon adsorption. These precipitates can foul the downstream equipment and interfere with treatment removal efficiency. Furthermore, without such treatment, these precipitates can form in injection wells and result in system failures. Iron and manganese concentrations in the influent water as low as 5 mg/1 may require this type of treatment; however, other factors such as pH and the distribution and concentration of anions in the water will also dictate the potential for these metal precipitates to form. Following their formation, the removal of the metal precipitates is typically achieved using sand filtration.

A process flowsheet for the addition of potassium permanganate followed by sand filtration is shown in Figure 4-6. The permanganate addition can occur directly into the influent line of the sand filter prior to an in-line static mixer, or it can be added with the polymer as part of the chemical coagulation and flocculation treatment step. Sand filtration typically consists of a sand column, pumps, a backwash system, and associated piping and tanks. The sand filter unit itself that is shown in Figure 4-6 represents a generic unit which is operated in a down flow mode; however, there are many alternative sand filtration process configurations that are available including some with a continuous backwash system. If backwashing is required, then the sand filter will be out of service during the backwash cycle which can last between 30 to 60 minutes. As such, the influent water treatment would have to cease during this cycle unless a stand-by sand filter is available. Permanganate addition and sand filtration would typically be required prior to additional treatment such as air stripping, carbon adsorption or chemical oxidation.

The exact threshold concentrations for iron and manganese, i.e., the concentrations below which their removal is not required, are not known at this time for the individual downstream treatment technologies. However, generally speaking, it is believed that these concentrations may be in the range of 1 to 5 mg/1. Furthermore, permanganate addition is not particularly effective in removing other metals from the water. In many cases, the insoluble metal precipitates are the hydroxide or sulfide forms of the metals and they require the addition of chemical additives such as lime or sodium sulfide. These additives can most effectively be added to the water as part of the chemical coagulation and flocculation treatment step. At the same time, some concurrent oxidation of organic contaminants does occur during the addition of permanganate to the water. While this may add some benefit to the overall treatment scheme, it also results in an additional consumption of the reactant and can substantially increase the operating cost of the treatment. This may not be a problem except that this oxidation may not represent the most cost-effective means for the removal of dissolved organic contaminants from the water.

The backwashing of the sand filter produces a solids sludge that must be properly managed. Typically this sludge is dewatered and thickened, to reduce its moisture content, and then managed as a solid waste.

It is unlikely that treatment will be complete following this treatment step since it is generally used as a pretreatment step for downstream treatment technologies. However, sand filtration could be used alone as a tertiary process for the removal of insoluble materials should it be needed to meet effluent discharge limits for total suspended or fixed solids. In these instances, .there would be no need for the addition of permanganate or any other chemical additives.

Removal of Volatile Organic Compounds

Figure 4-7 presents the process flowsheet for air stripping. Air stripping is typically used to remove VOCs, such as benzene and toluene, and consists of a packed air stripping tower with an air source (blower), tanks, pumps and associated piping. The air stripper offgas contains the VOCs and may require subsequent treatment depending upon federal, state, and local air regulations. Typically, if treatment of the offgas is required, it can be accomplished using either modular activated carbon units or catalytic oxidizers. Air stripping can be used as a stand alone treatment process if only treatment of the VOCs is required to achieve the effluent discharge limits. However, it is often used as a pretreatment process prior to carbon adsorption, biological oxidation, or chemical oxidation. In either case, the removal of oil and grease, suspended solids, and dissolved iron and manganese is often required to ensure efficient operation of the unit.'

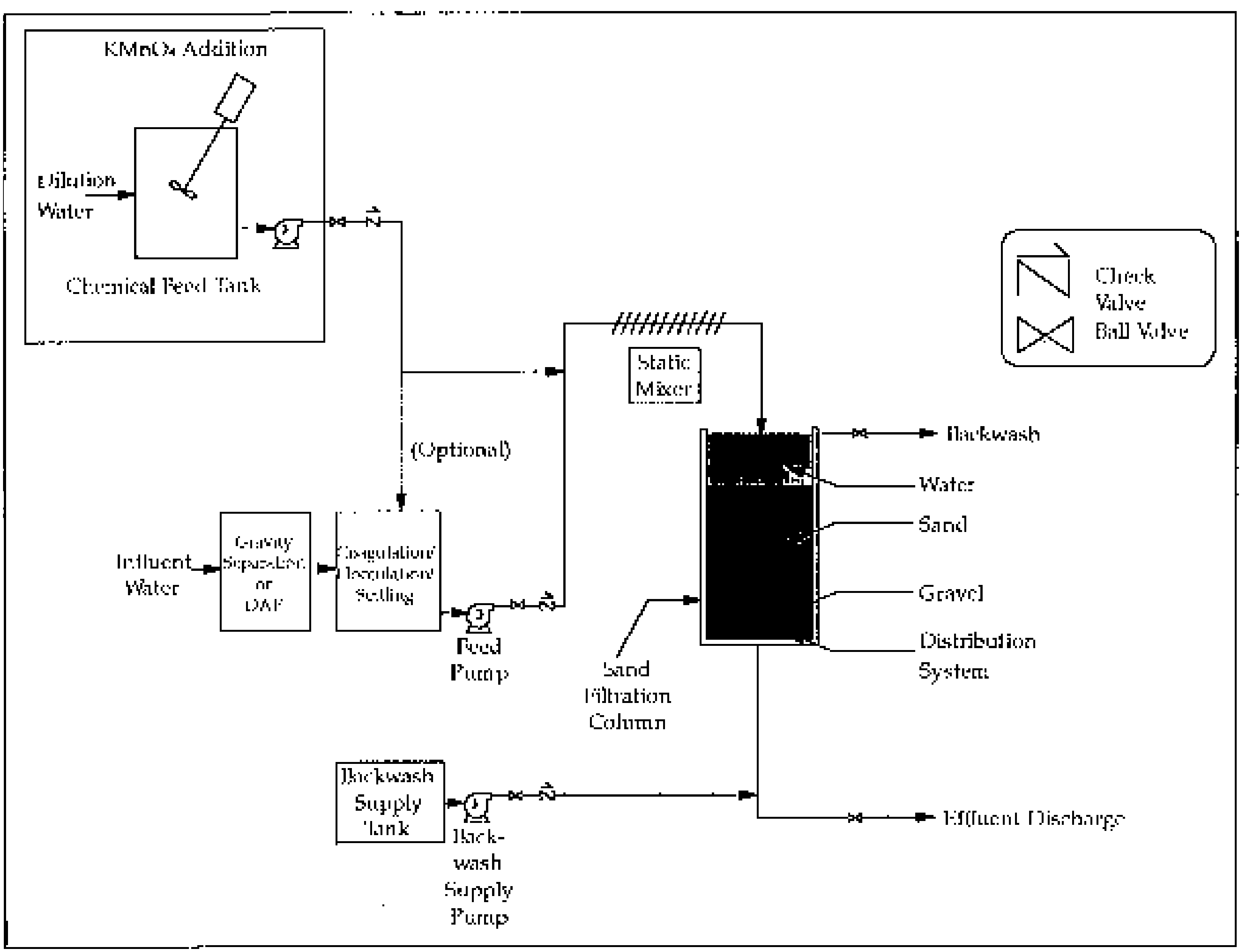

$KMnO_4$ Addition
Dilution Water
Chemical Feed Tank
(Optional)
Influent Water
Gravity Separator or DAF
Coagulation/ Flocculation/ Settling
Feed Pump
Static Mixer
Sand Filtration Column
Backwash Supply Tank
Back-wash Supply Pump
Backwash
Water
Sand
Gravel
Distribution System
Effluent Discharge
Check Valve
Ball Valve

Figure 4-6. Process Flowsheet for Metal Oxidation Followed by Sand Filtration.

The efficiency of air strippers becomes marginal as the volatility of the contaminants decreases. For the less volatile contaminants, steam stripping can enhance their removal by increasing the temperature and their respective vapor pressures. There are patented air and steam strippers that are currently available that claim significant removal of contaminants which were previously considered to pass through these systems untouched. However, there are no data in the public literature that support these claims for contaminated water from MGP sites.

The generation of an offgas that requires treatment and that results in a discharge to the atmosphere has the potential to complicate the permitting of the water treatment system. Historically, air permits have required the collection of background air quality data, an estimation of the contaminant emissions, and the modeling of the emissions to permit an analysis of their impact on the local and regional air quality. With the recent revisions to the Clean Air Act and the heavy emphasis on air toxics, these permit requirements may be even more stringent. Furthermore, the treatment of the offgas results in the generation of secondary environmental residuals such as spent activated carbon or spent catalysts. The management of these materials also contributes to the overall cost of water treatment.

It should be noted at this point that the presence of VOCs in the water has the potential to complicate the treatment of contaminated water from MGP sites. First, the presence of benzene in the contaminated water may make it a RCRA hazardous waste under current regulations if its concentration exceeds 500 ppb. While this does not affect the technical capability to treat the water, it does introduce additional permitting and other regulatory hurdles which must be addressed and which will no doubt increase the cost of treatment. For example, the spent carbon used to treat the stripper offgas could itself be considered a hazardous waste because of the hazardous classification of the water. Second, the evolution of offgases that contain VOCs has the potential to eliminate the ability to use open systems such as biological activated sludge and aeration tank systems for treatment of the water since these units may be unacceptable to the regulatory permitting agencies, although this would have to be analyzed on a case-by-case basis. For this reason, if biological oxidation in systems that are open to the atmosphere is being considered as a remedial treatment option, air stripping may be required to eliminate the VOCs prior to its use.

Air stripping is generally considered a relatively inexpensive treatment option compared to other methods for the treatment of organic contaminants. However, when the secondary environmental issues are addressed, the capital cost associated with their management can be nearly equivalent to the stripping process itself and the operating and maintenance costs can be an order-of-magnitude higher.

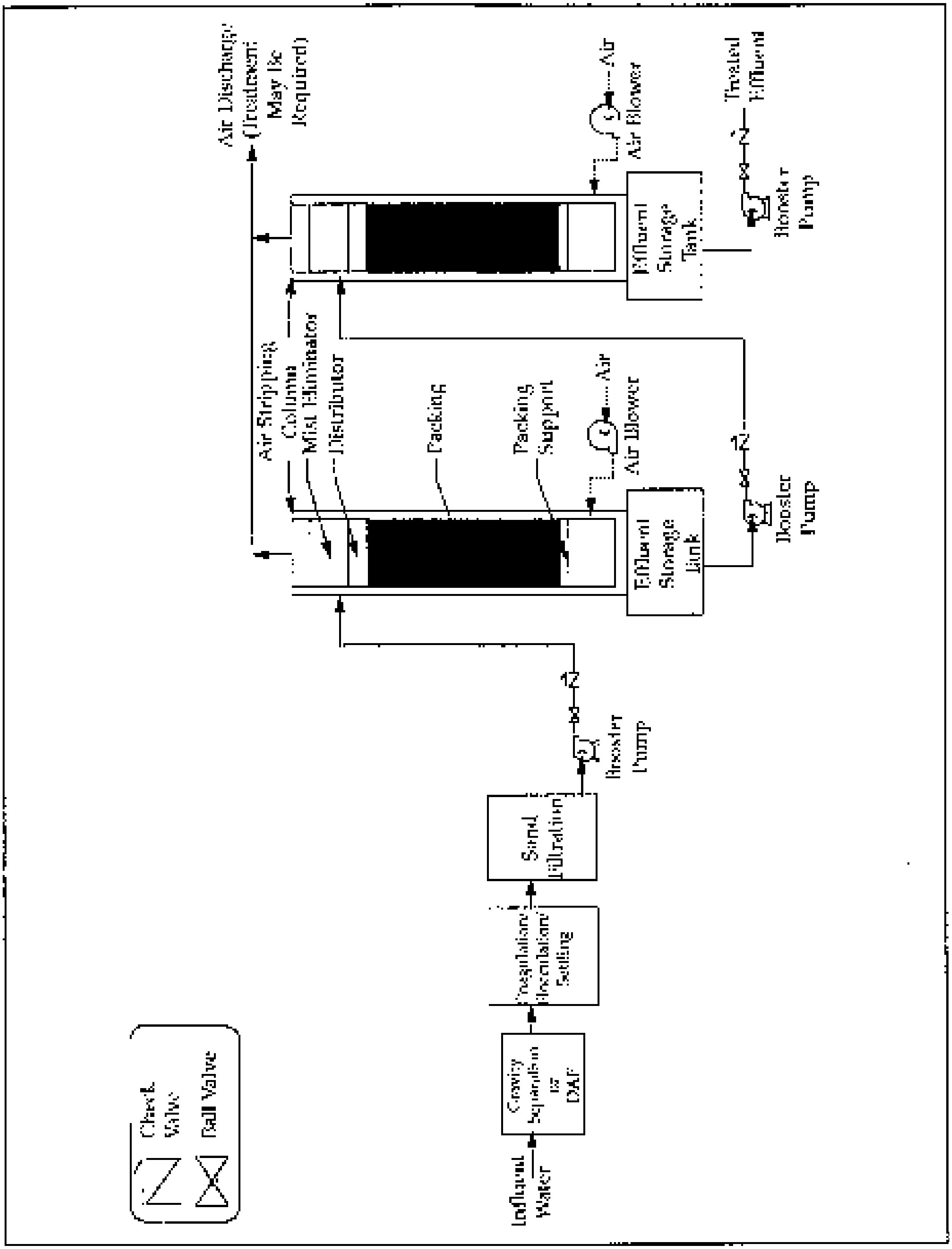

Check Valve
Ball Valve
Influent Water
Gravity Separation or DAF
Coagulation/ Flocculation/ Settling
Sand Filtration
Booster Pump
Air Stripping Column
Mist Eliminator
Distributor
Packing
Packing Support
Air
Air Blower
Effluent Storage Tank
Booster Pump
Air Discharge (Treatment May Be Required)
Air
Air Blower
Effluent Storage Tank
Booster Pump
Treated Effluent

Figure 4-7. Process Flowsheet for Air Stripping.

Removal of Non-Volatile Organic Compounds

The treatment of nonvolatile organic compounds can be addressed using three readily available and conventional treatment options: (1) carbon adsorption, (2) biological oxidation, and (3) chemical oxidation. The distribution of the non-volatile organic compounds will determine which of these options is best suited for the specific application. For example, a predominance of phenolic compounds and 2-, 3-, and 4-ring PAHs in the water would suggest that biological oxidation would perform well and may be less expensive than activated carbon or chemical oxidation. On the other hand, the presence of chlorinated organic compounds or 5- and 6-ring PAHs may favor the use of carbon adsorption or chemical oxidation over biological oxidation. The chlorinated compounds are more resistant to aerobic biological treatment and the heavier PAHs report to the sludge in the biological reactor and may interfere with its subsequent management.

Similarly, the distribution of the VOCs and dissolved inorganic compounds may also influence which remediation technology is best suited for the treatment of the non-volatile organic compounds. The presence of the VOCs may eliminate the ability to use the biological systems that are open to the atmosphere and the presence of complex cyanides may require the use of chemical oxidation (with UV light) as the primary approach for water treatment. It should be emphasized that many of the VOCs will also be treated concurrently with the non-volatile organic compounds. However, the extent of treatment that is required will depend upon the contaminant concentrations in the influent water and the extent that VOC removal was achieved in upstream treatment technologies (i.e., air strippers). The extent of VOC treatment that occurs prior to the treatment of the non-volatile organic compounds will vary from site to site and will be determined primarily by permitting issues and economics.

Carbon Adsorption

In adsorption processes, selected dissolved contaminants are transferred to a solid adsorbent as a result of weak chemical bonds between the contaminant and "active sites" on the surface of the adsorbent. For aqueous phase activated carbon treatment, the primary driving forces for adsorption are a combination of the hydrophobic nature of the contaminant and the affinity of the contaminant for the carbon. The adsorption of a specific chemical will depend on the carbon properties, the physical and chemical characteristics and the concentration of the contaminant, the overall characteristics of the aqueous phase, (e.g., other contaminants in solution) and the residence or contact time.

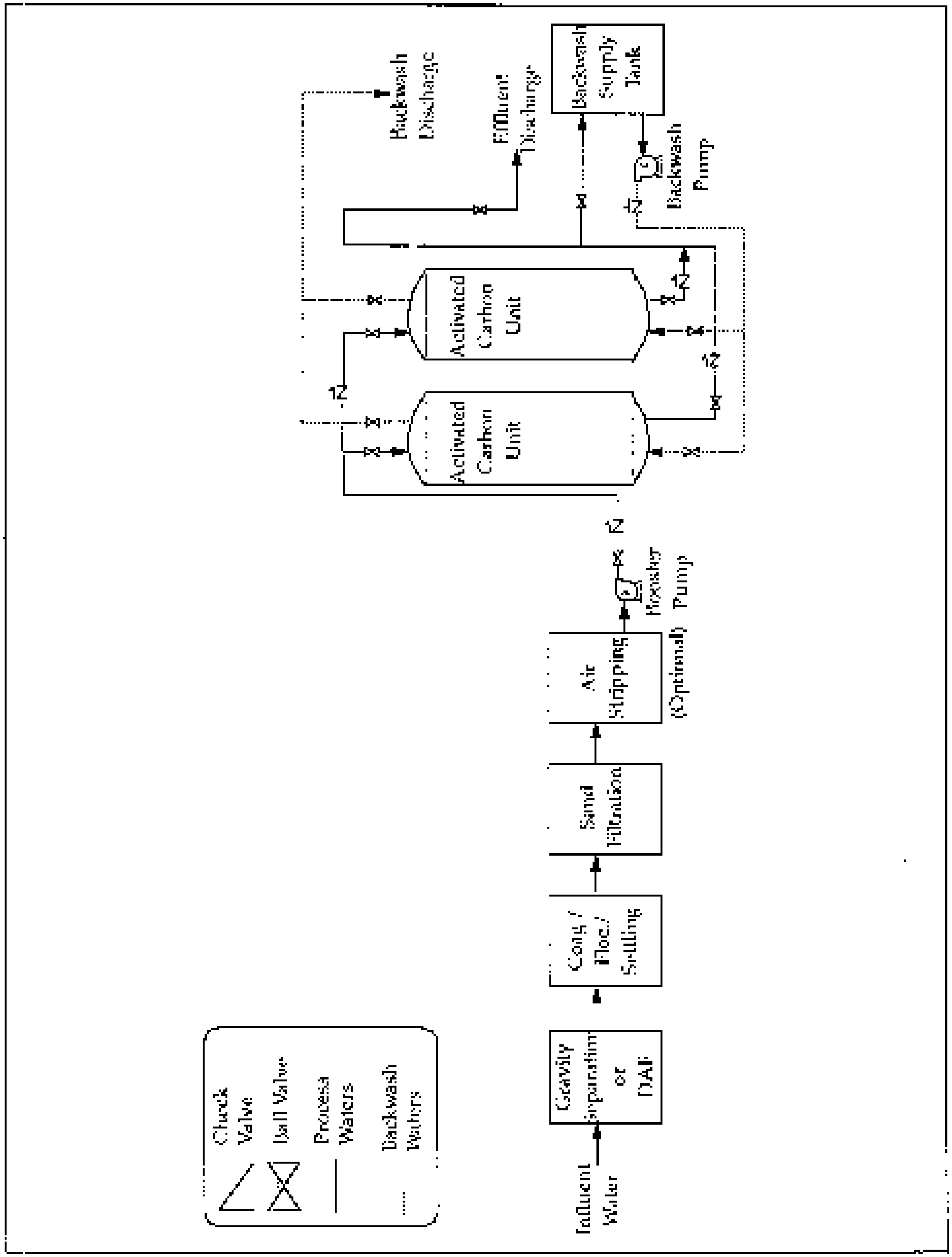

Influent Water
Gravity Separation or DAF
Coag / Floc / Settling
Sand Filtration
Air Stripping (Optional)
Booster Pump
Activated Carbon Unit
Activated Carbon Unit
Backwash Discharge
Effluent Discharge
Backwash Supply Tank
Backwash Pump
Check Valve
Ball Valve
Process Waters
Backwash Waters

Figure 4-8. Process Flowsheet for Carbon Adsorption.

The carbon adsorption flowsheet is presented in Figure 4-8. The flowsheet consists of a series of two carbon adsorbers, pumps, a backwash system, tanks, and associated piping. Gravity separation, chemical coagulation and flocculation, permanganate addition and sand filtration, or a combination thereof, is normally required prior to carbon treatment to remove free-phase hydrocarbons, suspended solids, and selected dissolved metals. If adequate pretreatment is provided, then backwashing of the carbon columns may be reduced and, possibly, eliminated. This has the potential to reduce the secondary costs associated with the backwash operation including the management of the sludge that is generated. This cost tradeoff would have to be analyzed to determine if the money would be better spent in the upstream pretreatment of the water or in the operating cost of the carbon adsorption system. Another cost trade-off that should be analyzed is the impact of air stripping on the carbon usage. For example, the organic loading to the carbon columns will be reduced by an air stripper and thereby reduce the carbon usage. However, this cost reduction will be countered by the cost of the air stripper and its ancillary equipment.

Carbon adsorption is generally regarded as the universal treatment technology for organic-contaminated water. However, because it is non-selective, its consumption may be excessive if there is a significant organic-loading in the water. This feature also will make it difficult to achieve a high degree of treatment and a stringent discharge limit for a specific organic contaminant. The pH of the influent also has a dramatic effect on the effectiveness of the adsorption process. Lastly, regeneration of the carbon is required as is the backwashing of the column to prevent excessive pressure drops. These activities can add significant costs to the use of this treatment technology.

Biological Oxidation

The biological oxidation of the contaminated water can be achieved in anyone of three configurations: (1) conventional activated sludge, (2) aeration tank, and (3) fluidized bed reactor. For the most part, each of these configurations requires that the water be pretreated in the same general manner as shown in Figure 4-8 for carbon adsorption. However, the extent of pretreatment that is required may vary to some degree among these three treatment options. For example, since plugging is much less of an issue for the biological treatment reactors, the removal of the dissolved iron and manganese may be less of an issue. However, this may not be the case for the fluidized bed bioreactors which require narrow particle size distributions for the adequate fluidization of the solids in the reactor. Chemicals which can be treated in biological units include conventional pollutants (e.g., biological oxygen demand or BOD and chemical oxygen demand or COD), phenolics, PAHs, VOCs, free and weak-acid dissociable cyanide, and ammonia.

Conventional Activated Sludge. Activated sludge processes use a biological slurry containing an active mass of bacteria (i.e., biomass) to achieve microbial oxidation and assimilation (treatment) of most organic and selected inorganic chemicals in contaminated water. A typical process flowsheet of a conventional activated sludge system is shown in Figure 4-9. Following pretreatment, the influent water enters an aeration tank where it comes into contact with the bacterial culture, which is maintained in suspension. The aeration tank contents are called the mixed liquor. Under proper conditions, the microorganisms in the mixed liquor convert the organic contaminants into microbial cells, carbon dioxide, and water. The treated mixed liquor passes from the aeration tank to a settling tank (clarifier) where the microbial solids or activated sludge are then separated from the treated effluent and the clarified effluent is discharged. Prior to discharge, additional treatment of the effluent may be needed to meet specific discharge requirements. Such polishing treatment may include sand filtration and/or activated carbon adsorption. The settled sludge from the clarifier is usually concentrated, via gravity thickening, and most is recycled back to the aeration tank, with the remaining portion managed as a waste (wasted). The portion of sludge returned to the aeration basin is referred to as recycle sludge, and is used to maintain a desired concentration of organisms in the aeration tank.

One of the main criteria which determines the applicability of activated sludge treatment is the concentration of organic contaminants present in the influent water. Typically, the influent water must contain a BOD_5 (five-day biological oxygen demand) concentration of at least 40 mg/L which is needed to sustain a viable bacterial mass in the system. Influent organic concentrations less than this would require use of an alternative biological treatment process.

MGP site groundwater has been directly discharged to activated sludge treatment units which have been part of a POTW. This has been done in the field using both pilot- and full-scale systems. The results of these efforts indicate that groundwaters can be successfully managed in these systems with little impact on standard operation. The pilot-scale study results have been extensively reported by the Gas Research Institute [Gas Research Institute, 1989a] while the field-scale study was conducted by a utility in New York State to support a feasibility study for a specific MGP site. In addition, this management option has been used extensively throughout the United States for MGP site excavation water which has been generated during the remediation of MGP sites.

Aeration Tank. Biological oxidation in an aeration tank is similar to that in an activated sludge treatment system except that there is no recycle of the activated sludge. As such, the aeration tank process makes no provisions for the settling and recycle of this biomass and the length of time that the water remains in the tank, lagoon or basin must be sufficiently long to allow for growth of the microorganisms. This residence time is generally four to five times longer than that for a conventional activated sludge system.

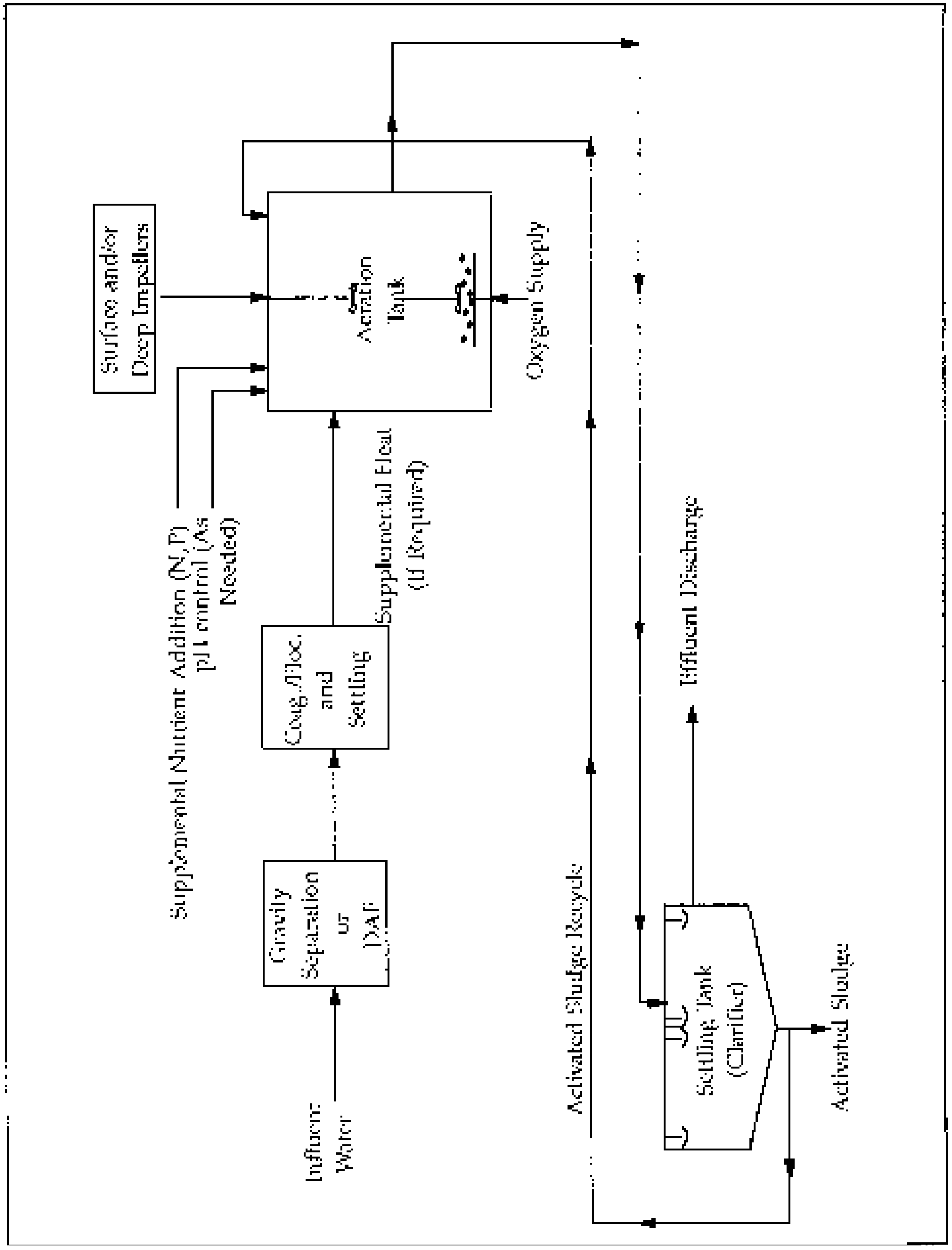


Figure 4-9. Process Flowsheet for Conventional Activated Sludge System.

The aeration tank configuration contacts an active mass of bacteria with the influent water in a stirred tank into which air is injected. In this tank, the organic components of the influent water serve as carbon and energy sources for microbial growth, and are converted into microbial cell tissue and oxidized end products such as carbon dioxide and water. After a specified time in the aeration tank, the treated effluent is discharged. The biological solids, generated during the oxidation of the organic contaminants, are suspended in the treated effluent. The use of the aeration tank system can be combined with a solids removal system, such as filtration, if the biological solids cannot be disposed of with the treated effluent. Figure 4-10 shows a process flowsheet for a typical aeration tank system.

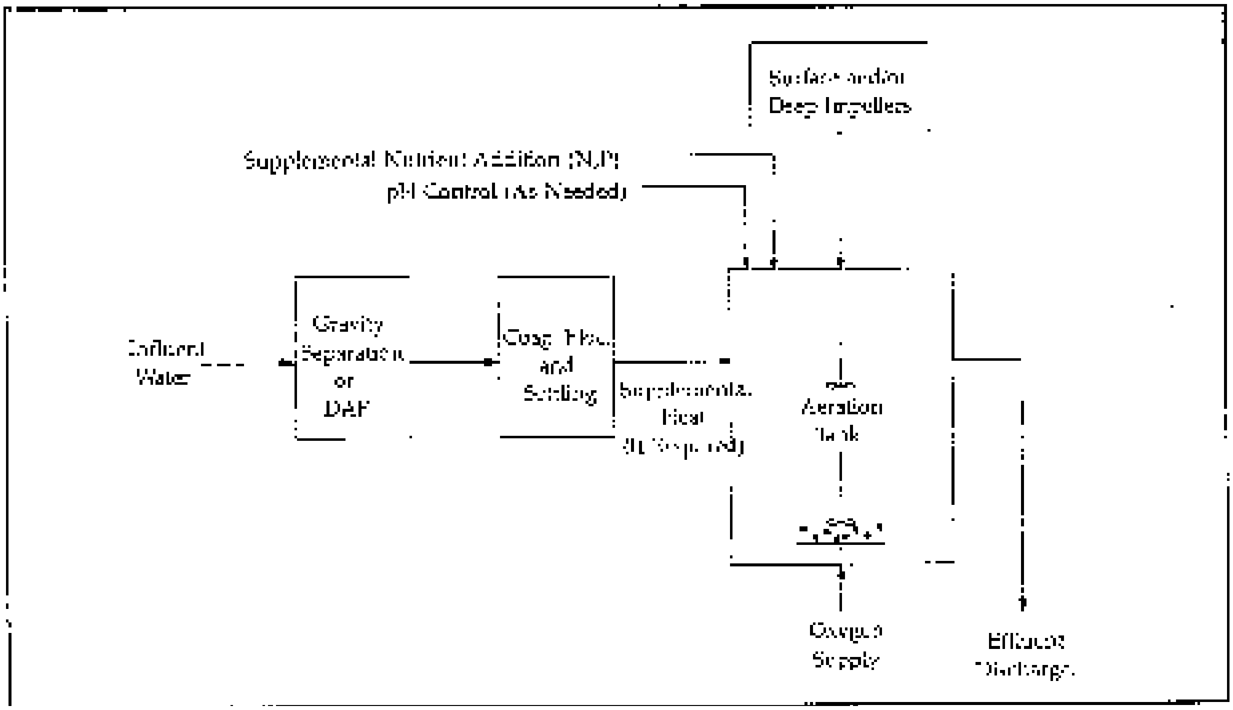


Figure 4-10. Process Flowsheet for an Aeration Tank System.

One advantage of the aeration tank system is that it can provide good treatment for all biodegradable compounds, if the system has been properly designed and is operated under normal conditions. Another advantage is that the process can handle minor fluctuations in influent water quality. Small changes in organic loading in the influent water usually will not cause a problem; however, if there are substantial changes in the incoming contaminant concentrations on a routine basis, upset conditions may occur and some form of flow equalization should be incorporated into the treatment system. Lastly, another advantage is the lower operating and maintenance costs when compared to an activated sludge system, mainly because there is no sludge disposal or handling. However, solids removal from the treated effluent may be needed and may represent an additional cost.

Fluidized Bed Bioreactor. Fluidized bed biological treatment is achieved by passing contaminated water through a reactor that contains a suspended bed of material such as sand, coal, or activated carbon upon which an active microbial film (biomass) has developed. This active biomass biologically decomposes contaminants in the water. If activated carbon is used as the fluidized media, the process of adsorption and subsequent biodegradation of the adsorbed contaminants occurs, thus achieving an effluent containing generally non-detectable concentrations of organic contaminants. In addition, the process can be operated as a closed system such that VOCs which pass through the reactor (i.e., are not adsorbed or biodegraded) do not escape to the atmosphere but are recycled to the reactor for further treatment. Lastly, the activated carbon that is used in the process is regenerated in place as the adsorbed contaminants are biodegraded. Figure 4-11 provides a process flowsheet of a fluidized bed biological treatment system.

The experience base for the application of this technology to contaminated groundwaters from MGP sites is growing [Gas Research Institute, 1993]. In fact, current plans are to treat groundwater in a fluidized bed Bioreactor system in 1994 at two MGP sites, one in Stroudsburg, Pennsylvania, and the other in Baltimore, Maryland. The field application in Maryland was preceded by a three-month pilot scale study which successfully treated 15 to 20 gpm of MGP site groundwater.

Chemical Oxidation

Both ozone (O_3) and hydrogen peroxide (H_2O_2) are oxidizing agents which have been used to oxidize organic contaminants in water. The use of UV light in combination with an oxidizing agent enhances the reactivity of these chemicals. In both cases (i.e., with or without UV light) organic contaminants can be converted to carbon dioxide and water given sufficient reaction time and oxidant dosage. The combination of oxidizing agent and ultraviolet light is capable of treating the same organic contaminants as chemical oxidation alone.

Figure 4-12 presents a generic process flowsheet for UV/chemical oxidation. UV/chemical oxidation can stand alone as a groundwater treatment process; however, gravity separation, chemical coagulation and flocculation, and permanganate addition and sand filtration will most likely be required as a form of pretreatment prior to its use. This pretreatment will ensure improved and consistent operation of the units. It should be noted that chemical oxidation can be accomplished with or without ultraviolet light. However, the combined treatment is typically viewed as more capable of treating the full range of contaminants that are present in the MGP site water (one exception may be complex cyanides, see Section 4.2.3).

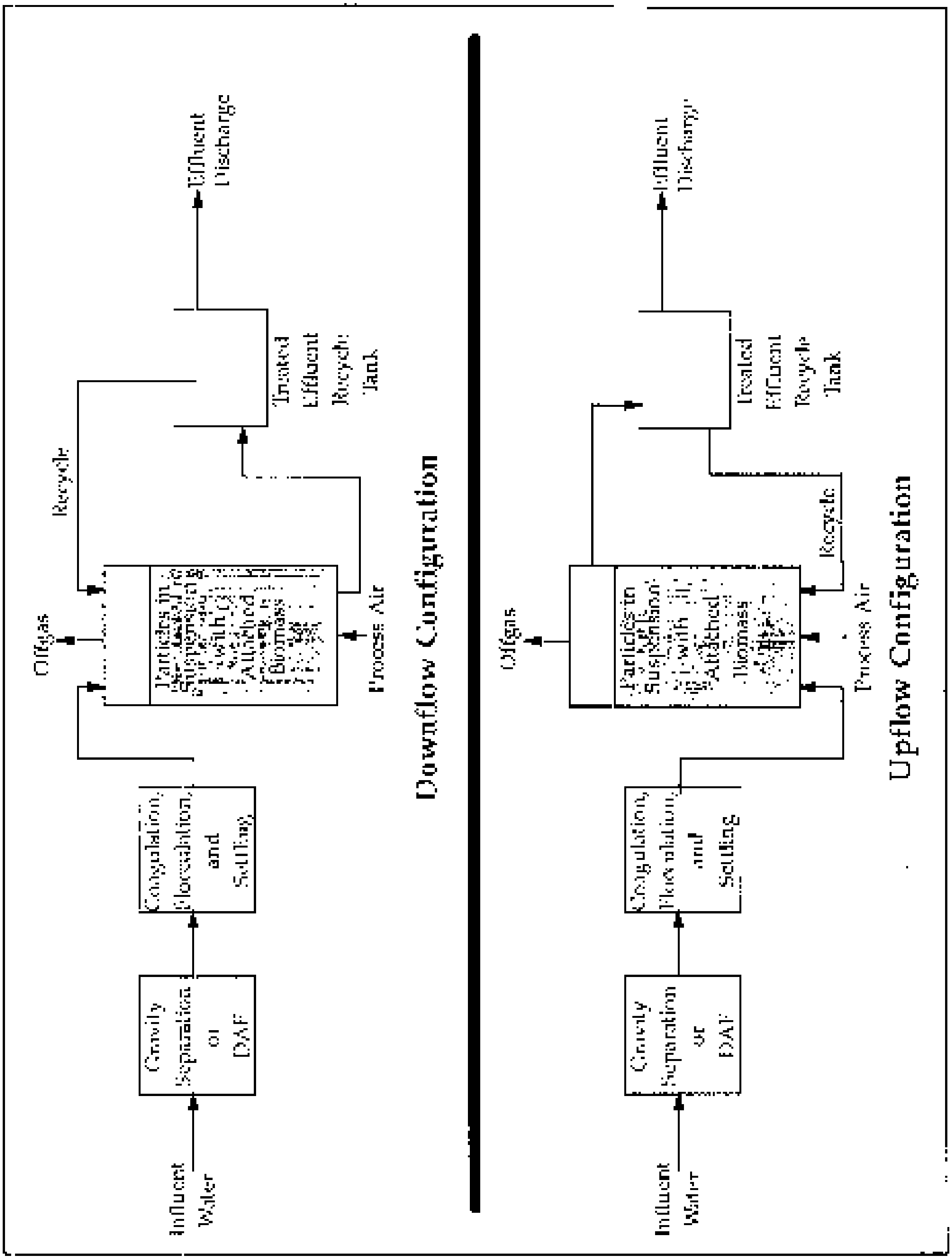

Influent Water
Gravity Separation or DAF
Coagulation, Flocculation, and Settling
Offgas
Recycle
Particles in Suspension with Attached Biomass
Process Air
Treated Effluent Recycle Tank
Effluent Discharge
Downflow Configuration
Influent Water
Gravity Separation or DAF
Coagulation, Flocculation, and Settling
Offgas
Particles in Suspension with Attached Biomass
Recycle
Process Air
Treated Effluent Recycle Tank
Effluent Discharge
Upflow Configuration

Figure 4-11. Process Flowsheet for a Fluidized Bed Biological Treatment System.

The degree to which UV/chemical oxidation oxidizes organic contaminants is dependent upon: (i) the oxidant dosage, (ii) the initial concentration of chemicals in solution, and (iii) their molecular structure. Review of the literature data suggests that there is competition among different chemical groups for the available oxidant and absorbance of UV light. The process effectiveness decreases as the turbidity of the water increases. The process appears to be well suited for reduction of phenolics, PAHs, and cyanide. For cyanide, ozone in the presence of UV light also has the potential to break the iron-cyanide and other metal-cyanide complexes, which cannot be accomplished biologically. Additional work is required to establish the capability of this technology to treat chemical compounds at site-specific concentrations.

The cost of treatment using UV light, 03, and/or H202 can be substantial with significant capital and operating costs. The operating costs are driven by the contaminant concentrations that are present in the water since the oxidation process is non-selective. In addition, the replacement of the ultraviolet lights may also be a significant cost depending upon the effectiveness of the pretreatment options.

4.2.3 REMOVAL OF DISSOLVED INORGANIC CONTAMINANTS

Dissolved inorganic contaminants in contaminated water at MGP sites typically consist of a mixture of cations, such as metals and ammonia, and anions, such as cyanide, sulfate, nitrate, and carbonate. For the most part, the focus for treatment has been on selected metals and cyanide. The metals of interest vary from site to site but almost always include iron and manganese. As previously discussed (Section 4.2.2, Pretreatment), these metals are targeted because they tend to form precipitates that result in the plugging or fouling of process equipment. Other metals such as lead, mercury, or arsenic may be present in the water although they have not been identified to date as problems at MGP sites. Stated differently, the concentrations of these and other dissolved metals in the contaminated water have not required its treatment nor prevented its discharge. Nevertheless, site-specific water quality regulations may require a remediation strategy to address these contaminants as part of the permitting process for the discharge of the treated effluent.

Cyanide concentrations, on the other hand, have been identified as an issue. The majority of the total cyanide that is present in contaminated water at MGP sites forms complexes with metal cations such as iron and nickel. These cyanide-metal complexes are quite stable and are often referred to as "complexed cyanides." The most dominant form of complexed cyanides in MGP site water is iron-cyanide which stems from the dominance of this cyanide form in the purifier box wastes. In addition to the complexed cyanides, there are also low concentrations of free cyanide (HCN and CN^-) and weak acid dissociable cyanides which includes free cyanide as well as metal-cyanide complexes which dissociate readily upon dilution or mild acidification (e.g., Cd^{+2}, Pb^{+2}, Zn^{+2}).

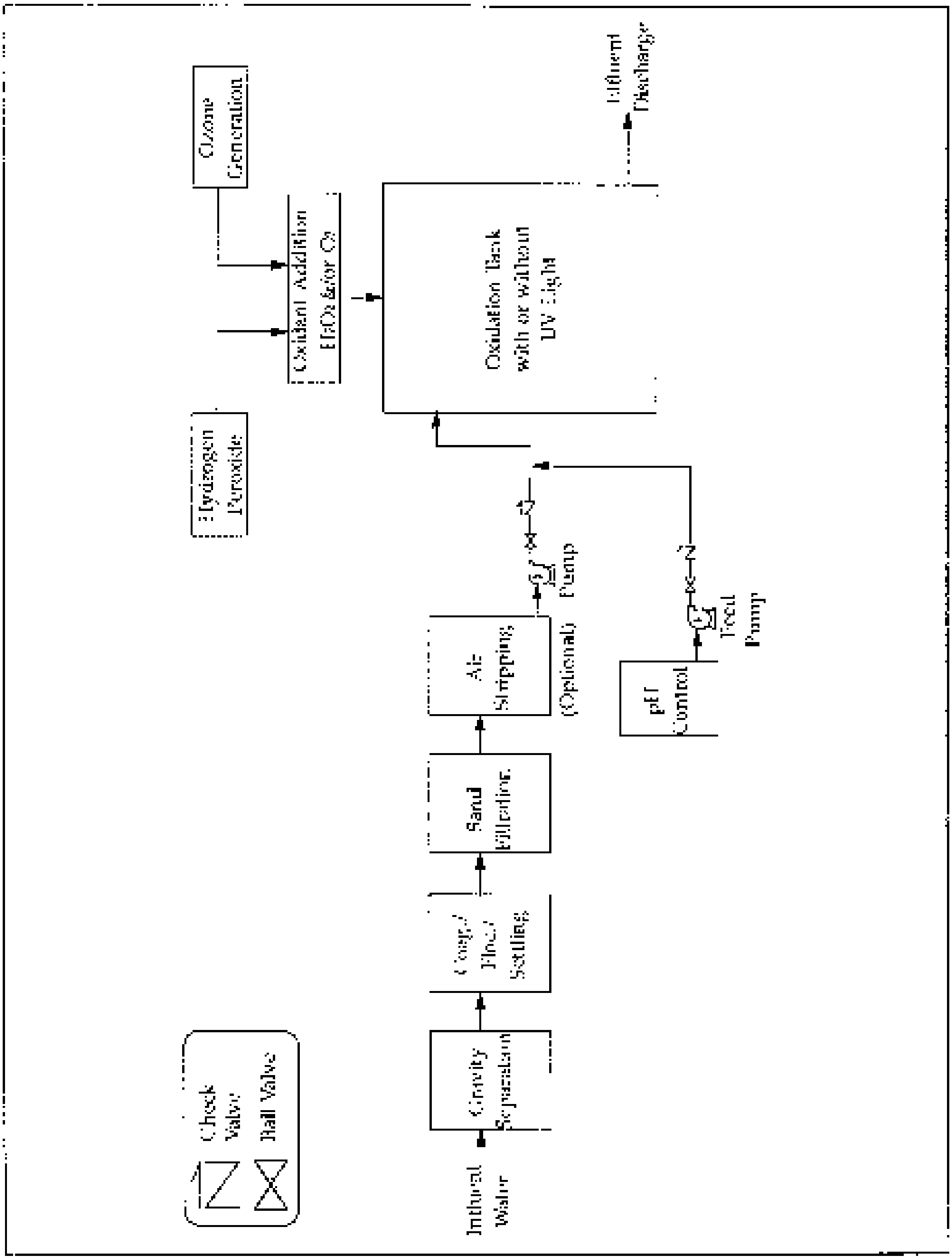


Figure 4-12. Process Flowsheet for UV/Chemical Oxidation

It is interesting to note that many water discharge regulations specify concentration limits for both total cyanide as well as "cyanide amenable-to-chlorination." The latter group of cyanides includes all metal cyanides except the most strongly bound metallocyanide complexes (e.g., Fe^{-2}, Fe^{+3}, and some noble metals such as silver and platinum).

Since the free and weak acid forms of cyanide are not the dominant form of cyanide in MGP site waters, their treatment is not discussed in detail in this report. However, these chemical forms of cyanide can be a factor in the development of remediation strategies for contaminated water from MGP sites since they are specifically identified as part of several water quality criteria which have been established for fresh and marine water environments. For example, the Federal water quality criteria for marine environments specify concentrations for free cyanide of 1 ppb based upon acute environmental effects (U.S. Environmental Protection Agency, 1986). Should these criteria require the treatment of these contaminants at an MGP site, this treatment can be accomplished using many conventional treatment technologies such as biological oxidation or chemical oxidation (e.g., ozonation or alkaline chlorination). In contrast, the strongly complexed cyanide compounds, which are the predominant form of cyanide at MGP sites, are not specifically regulated due to their lack of impact to human health and the environment. However, since many of the environmental regulatory agencies do not distinguish between the various chemical forms of cyanide and, therefore, consider all cyanide as free cyanide, removal of these contaminants is often required. Unlike the free cyanide, the treatment options for these contaminants are limited and include only UV/chemical oxidation and ion exchange resins and, perhaps, carbon adsorption. Both ion exchange and carbon adsorption provide more selective treatment that UV/chemical oxidation. Furthermore, the most effective ion exchange resins are non-selective for covalent ions and have a tendency to be rapidly consumed due to the presence of non-cyanide ions such as sulfate, nitrate, or carbonate. Due to the release of hydroxyl (OH) ions during the ion exchange treatment, the treated effluent must be neutralized with the addition of acid.

UV/Chemical Oxidation

The use of UV/chemical oxidation to treat dissolved organic contaminants can result in the concurrent treatment of all forms of cyanide. If this treatment option is not used for the organic contaminants then it may be required solely for the management of the cyanide. However, the final decision regarding the selection of this technology will be based upon the overall treatment economics since it may be that a sufficiently high organic-loading could make the cost of UV/chemical oxidation prohibitive in comparison to the other organic treatment alternatives. In other words, it may make more economic sense to remove the dissolved organic contaminants prior to cyanide treatment and thereby use a smaller chemical oxidation reactor and -less chemicals and energy to achieve the desired degree of cyanide removal.

Carbon Adsorption

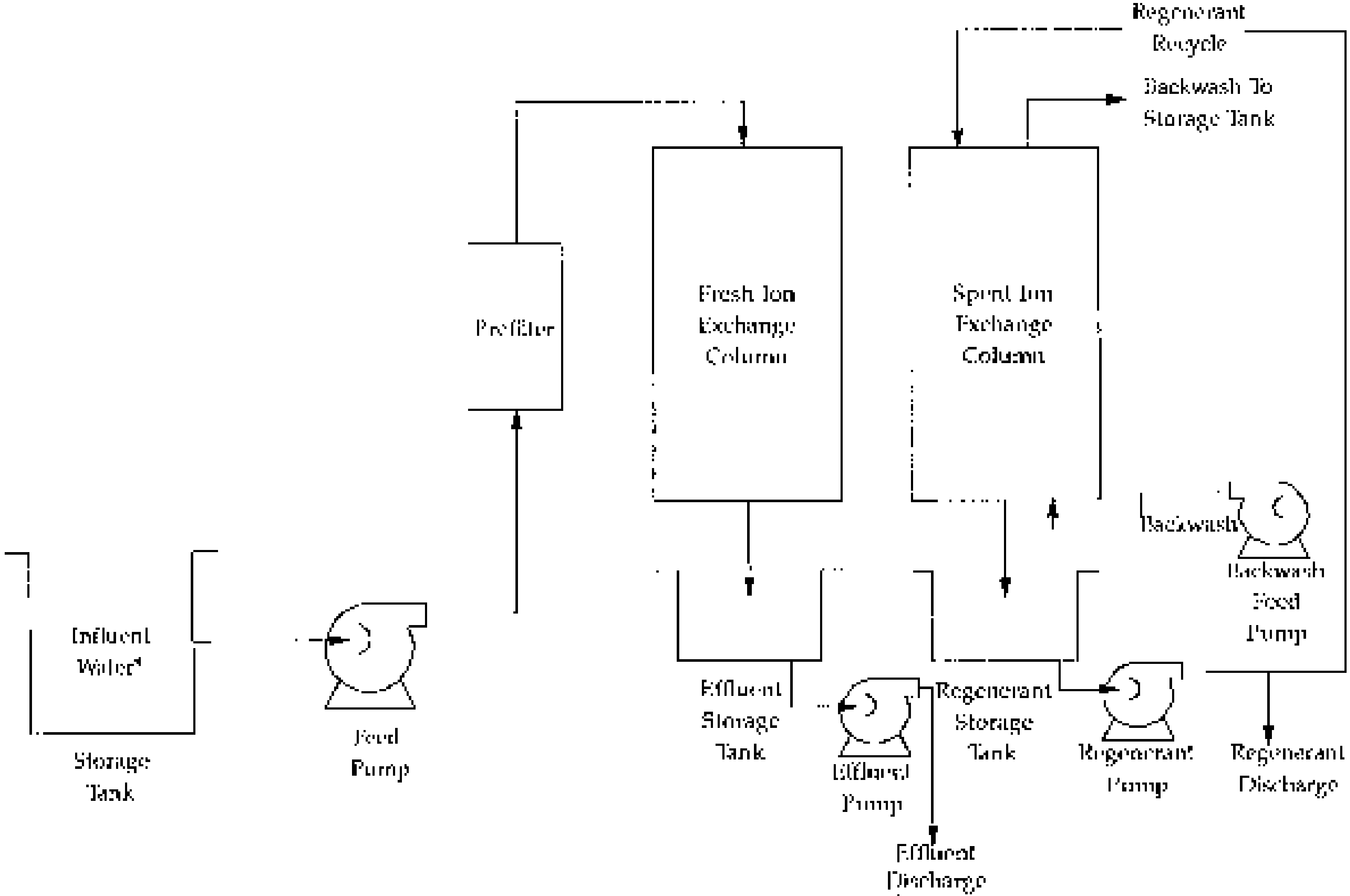
Similar to UV/chemical oxidation, carbon adsorption may also result in the removal of complexed cyanide during the treatment of dissolved organic contaminants. The efficiency of this method of treatment can be quite variable and is a strong function of the mixture of cyanide complexes and organic contaminants that are present in the water. For this reason, carbon adsorption is rarely used for the sole purpose of removing complex cyanides; rather, the cyanide treatment that is achieved is usually the incidental treatment that occurs concurrently with the reduction of dissolved organic contaminants in the water.

Ion Exchange Resins

Ion exchange is a separation process in which selected contaminant ions in an aqueous solution are removed when they attach to the surface of an ion exchange resin, displacing ions from the resin. In practice, ion exchange "beads" are placed in a column and untreated water is passed through them. Natural ion-exchange materials (zeolites) exist; however, most industrial processing uses synthetic resins, normally high-molecular-weight organic polymers, onto which chemical functional groups (e.g., sulfonic, carboxylic, phenolic, aminos) are added by chemical reaction. The contaminants which can be treated using ion exchange include inorganic cations, such as heavy metals and ammonia, and anions, such as cyanide and cyanide complexes. The process is also potentially applicable to ionic organic compounds such as phenolics.

A typical process flowsheet for an ion exchange system is presented in Figure 4-13. A storage tank is normally used to provide a surge volume in the system, thus allowing the operation of the system at a constant rate and sufficient time for coarse solids to settle from the feed water. Untreated water is pumped from the storage tank to the ion exchange columns. Pretreatment using carbon adsorption or filtration is often required to prolong the life of the ion exchange resin. If a large volume of water is to be treated, two sets of columns should be installed to provide uninterrupted system operation during periods of column regeneration. The treated water flows by gravity from the columns to a treated effluent storage system to allow for monitoring before discharge. Conductivity (a measure of total ion concentration) can be used to determine "breakthrough," at which time the columns are switched and the column with the spent ion exchange resin is regenerated.

With the mixed bed scheme, the regeneration of the ion exchange resin is accomplished as follows. The resin bed is first backwashed gently to remove suspended solids after which the resin bed is fluidized. Dilute hydrochloric acid is then pumped from storage through the bed in a direction that is countercurrent to the normal flow of the influent water. After a water wash, dilute sodium hydroxide (regenerant) is pumped through the bed to convert the anion resin back to the hydroxide form.



*After Treatment for Removal of Insoluble Materials and Soluble Organic Compounds.

Figure 4-13. Process Flowsheet for Ion Exchange System.

After another water wash, the column can be returned to service. The various acid, caustic, and wash regenerant solutions which now contain contaminants must be treated or otherwise managed. Methods of regeneration and the types of regenerate solutions that are used will vary according to the specialized type of resin that is used. There are non-regenerable resins that are available but these must be managed as a waste after they are spent.

Ion exchange applications at MGP sites have not been identified. Most performance data that have been reported are for water from plating processes which have high metal concentrations. However, an ion exchange process used to treat a condensate from a petroleum refinery achieved removal of hydrogen sulfide to <3 ppm, ammonia to 5 ppm and phenol to 20 ppm. It must be stressed that the performance of an ion exchange process is very dependent on the composition of the particular water that is treated. Although ion exchange has not been tested on contaminated water from MGP sites, a resin has been developed in the aluminum industry to deal with complex cyanides that are present in the leachates of potliners. Laboratory results indicate that this resin can remove the cyanide complexes that are present in MGP site water and field applications are now operational and will provide full-scale data in the near future.

4.2.4 pH ADJUSTMENT

The pH of the influent water continually fluctuates during its treatment. This is the result of the addition of chemicals as well as the generation of a variety of chemical reaction products. As such, to permit the final discharge of the water, it is often necessary to adjust the pH back to the neutral range (i.e., pH of 6.0 to 8.0). This is accomplished through neutralization of the effluent discharge.

Neutralization is essentially the mixing of an acid (low pH) or a base (high pH) with a liquid stream to produce a liquid with a neutral pH. The addition of a given neutralizing agent can be accomplished using either continuous or batch processes. The batch process allows for the greatest control because the pH of the batch can be monitored and the discharge delayed until the proper pH is attained. Unfortunately, because of storage requirements, the batch process is normally limited to waste streams with low flows. For medium to high flow streams, some form of a continuous process is used, requiring more elaborate control and chemical feed equipment. It should also be recognized that the neutralization process can result in the formation of precipitates or insoluble chemical sludges. These sludges must be properly managed before the treatment of the water can be considered complete.

5

EX SITU MANAGEMENT OF SOURCE MATERIAL AND CONTAMINATED SOIL AND SEDIMENT

Figure 5-1 presents several management strategies that depict the most common approaches to *ex situ* treatment which have been used for source material and contaminated soil and sediment at MGP sites. A brief description of each of these technologies is provided in Appendix A of this report. Since the focus of Figure 5-1 is on *ex situ* treatment, all of the strategies require' the removal of the contaminated materials prior to treatment and the final disposition of the treated materials. As previously noted, the methods that are available for material removal depend upon the characteristics of the material and its location and the final disposition of the treated materials will be based upon the extent of treatment that is achieved and the requirements of the governing regulatory agencies. Because of the importance of the materials removal and storage aspects of *ex situ* treatment, a brief discussion of the primary factors that influence their selection is provided in this section along with a similar discussion for the treatment technologies themselves.

5.1 REMOVAL AND STORAGE

The removal of source material and contaminated soil and sediment will require a wide range of methods and techniques. Although, a thorough review of these methods and techniques was also provided by EPRI [EPRI, 1991], a brief discussion of the more salient of these is provided here.

5.1.1 FREE-PHASE HYDROCARBONS (TARS)

The removal of the pumpable, free-phase hydrocarbons from either a subsurface structure such as a gas holder or the geologic subsurface can be accomplished using conventional and commercially available pumping systems. However, access to the wastes is significantly different for the two sources. On the one hand, the hydrocarbons in the structures can usually be accessed using existing valving arrangements or through the top of the structures. On the other hand, removal from the geologic subsurface generally requires the installation of recovery wells, hydrocarbon/water separation equipment, and intermediate storage tanks. This recovery effort can be further complicated by the presence of underground utilities, the non-homogeneity of the subsurface geology, and the limited hydrocarbon pumping rate which can be achieved.

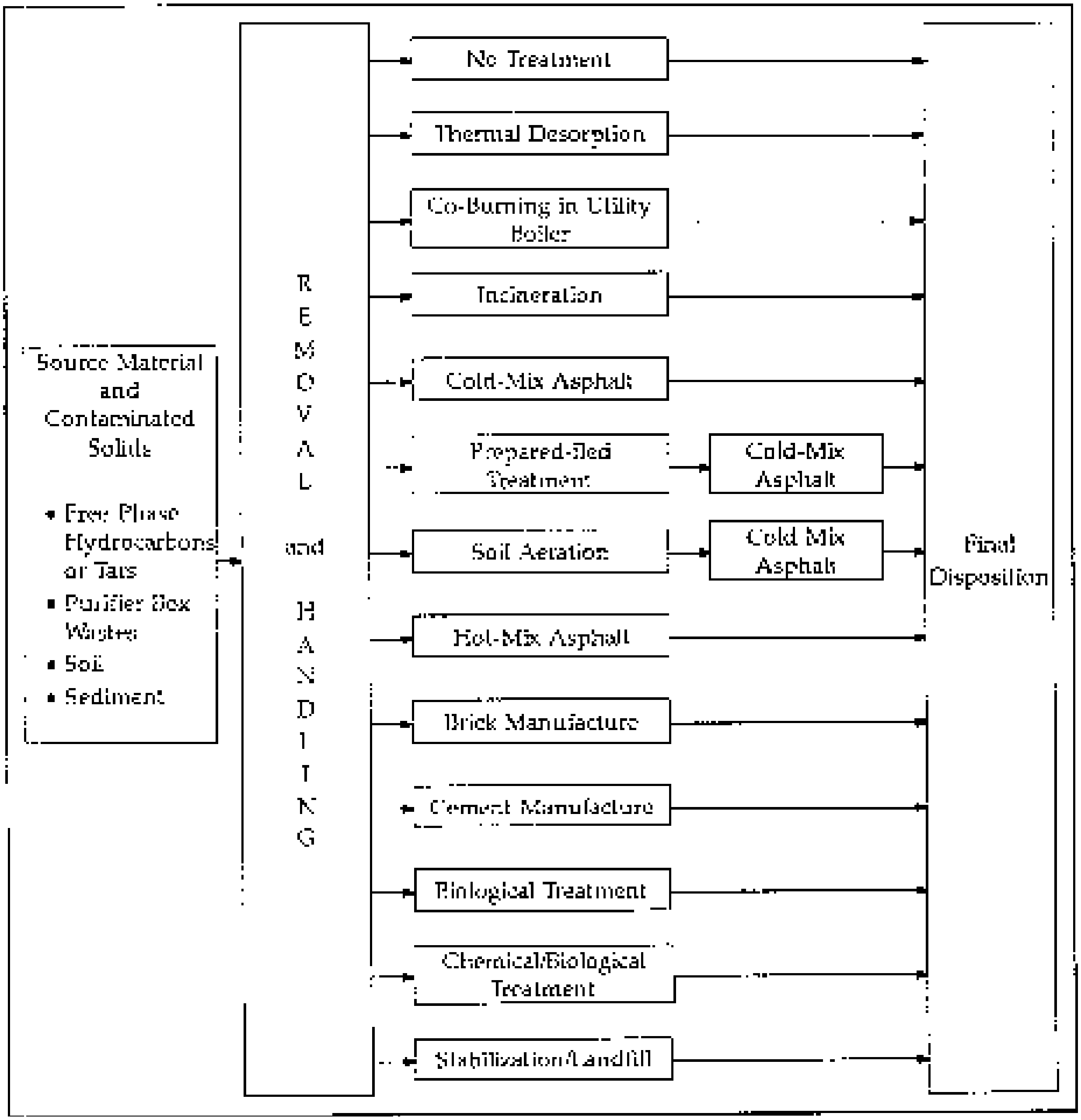


Figure 5-1. Candidate Management Strategies for Contaminated Solids at MGP Sites.

The removal of the non-pumpable free-phase hydrocarbons will require some type of excavation. For example, the removal of these materials from the bottom of an above-grade gas holder can be accomplished by cutting into the holder after all pumpable materials are removed, and using a backhoe and manual labor to scrape the tars from the holder bottom and sides. Alternatively, if the tar is present in a subsurface pit, a backhoe can be used directly to excavate the wastes. If the nonpumpable flee-phase hydrocarbons exist in locations which are more difficult to access, such as in deep subsurface deposits or at the bottom of subsurface gas holders, more extreme excavation techniques would be required. Of course, at extreme depths, excavation may not be possible at all, thereby forcing the examination of *in situ* management techniques.

Odors can be a significant management problem during the excavation and/or surface management of free-phase hydrocarbons. To date, several utilities have had to address odor problems. The most common options for odor management include the use of chemical foams or enclosed structures. The purpose of the foams is to reduce or eliminate the contact of the exposed hydrocarbons to the atmosphere. As such, the foams are applied throughout the excavation as new materials are exposed by the excavation equipment. The selection of the appropriate chemicals for use usually requires laboratory treatability tests. The major concerns with the chemicals are their ultimate fate in the environment and their cost. Alternatively, the excavations can be covered using temporary enclosures. These enclosures can be rapidly assembled and prevent odor by confining all volatile releases within the enclosure. This approach, however, can require Level B health and safety protection for the remediation personnel. Such protection may be required due to the emissions from the excavation as well as due to the exhaust emissions from the heavy equipment that is used for the excavation. In addition, it will most likely be necessary to ventilate the enclosure and to treat the exhaust air using carbon or other resins prior to its release to the atmosphere. This approach to odor management can be effective although it can also contribute significantly to the cost of the excavation.

Following removal, the non-pumpable flee-phase hydrocarbons should be stored in a contained area to prevent the localized spread of the contamination. This storage can usually be done on hard surfaces (concrete pads) surrounded by temporary berms. If this storage area is not covered, the berm should be sufficiently high to contain any rainfall runoff which may be produced during the storage period. However, some form of cover may be required to minimize the emission of VOCs and particulates and to reduce odor from the materials in storage.

5.1.2 PURIFIER BOX WASTES

For the most part, purifier box wastes were either shipped offsite or used as fill in the low areas of the site. As such, the onsite deposits are typically on the surface or in the very near subsurface. In these locations, removal can easily be accomplished using conventional excavation equipment such as backhoes and front end loaders. Deeper excavations, should they be required, will use equipment and techniques identical to those described for contaminated soil.

5.1.3 CONTAMINATED SOIL

Some form of excavation will be required to remove contaminated soil from the subsurface. Typically, if the soils are present on the surface or near-surface, i.e., within approximately 20 feet of the surface, removal can be accomplished using conventional backhoes. Beyond this depth, drag lines can be used or, alternatively, if the area of excavation is substantial, the backhoe can be taken into the excavation itself to reach the deeper soils.

Complications in the excavation often arise at MGP sites due to the presence of unstable soils, a shallow groundwater table or surface and subsurface site structures. If these conditions are encountered, other excavation approaches must be used to get access to the soil (e.g., use of retaining walls such as sheet piles or freeze walls and/or excavation dewatering techniques). For example, sheet piles have been used at several MGP sites as a means to excavate in unstable soils or beneath the groundwater table and, more recently, a freeze wail has been installed for this purpose. In the case of the latter, the freeze wall also was used to reinforce the structural integrity of the subsurface structure as its contents were removed. However, before utilizing these excavation techniques, it may be prudent to consider alternative remediation strategies that involve *in situ* management.

Odors may also be a problem during the excavation of highly contaminated soil. The management approaches for these materials are identical to those described previously for flee-phase hydrocarbons.

Following excavation, the contaminated soil can be stored on either a concrete pad or a lined area with a berm to control rainfall runoff. Again, consideration should be given to covering the soils to limit both volatile and particulate emissions into the atmosphere.

5.1.4 CONTAMINATED SEDIMENT

The removal of sediment from bodies of water can be accomplished using a number of excavation techniques. First, similar to soil, direct mechanical excavation using backhoes, draglines or clamshells can be used. This method is usually suitable for shallow streams with low flow velocities and lakes or ponds with contaminated sediment located within reach from the shoreline. One difficulty with mechanical excavation is that excessive turbulence can be created and result in the downstream movement of contaminants. However, silt screens can be installed downstream of the excavation activity to prevent and/or control this condition.

A second method of sediment excavation which can be used is the construction of temporary cofferdams to hydraulically isolate the sediment which is targeted for removal. If the area of contamination is along one bank of the stream, a single curved cofferdam can be installed that isolates the bank; however, if contamination extends across an entire stream, dual cofferdams may have to be installed to achieve diversion of the stream flow. The areas within the cofferdams can be dewatered prior to the removal of the sediment through natural drainage or the use of pumps.

The third method of excavation is hydraulic dredging with low turbidity equipment. These types of systems are capable of pumping materials containing 10 to 20 percent solids from the bottoms of water bodies. There are many different dredge designs for use on bottoms with different physical features. Care must be taken to employ the type of dredge system which will minimize turbidity and increase suction efficiency.

Following removal and prior to treatment or offsite transport, it is likely that the recovered sediment will require some form of dewatering. This can be accomplished using a variety of techniques, the most common of which are settling ponds, filtration systems, or the addition of stabilization agents.

5.2 TREATMENT AND DISPOSAL

Ex situ remediation strategies for the source material and contaminated soil and sediment that are shown in Figure 5-1 include thermal, physical/chemical, and biological treatment technologies. It is likely that no one technology will be capable of treating all of the different contaminated materials that may be present at an MGP site and that a combination of the various treatment options will be required to implement a fully-integrated site remediation. For example, incineration may be required for the treatment of free-phase hydrocarbons while thermal desorption may be needed to treat soil contaminated with tar and other organic contaminants. At the same time, spent purifier box wastes may be recycled into cement or bricks or perhaps placed in a landfill. In most cases, however, only a single treatment technology will be applied to each of the different contaminated solids. This is due to the excessive costs associated with the multiple handling and processing of heterogeneous mixtures of solids.

5.2.1 THERMAL TREATMENT

Thermal treatment involves a number of processes that use elevated temperatures to recover and/or destroy the contaminants that are present in the source material and contaminated solids. These processes focus on the treatment of organic contaminants and include thermal desorption, co-burning in utility boilers, and incineration. However, inorganic contaminants such as selected heavy metals, cyanide, and sulfur compounds can also be treated using these processes; however, with the exception of purifier box wastes, the treatment of these contaminants .usually occur incidentally as the removal of the organic contaminants is achieved.

Thermal desorption and incineration can occur at the MGP site itself/ (i.e., onsite) or at an offsite, fixed base facility. The selection of onsite or offsite treatment is dictated by a number of factors including, among others, the site location (e.g., urban or rural), the quantity of residuals, the distance to the nearest offsite treatment facility, the cost of offsite transportation and treatment, and differences in permit requirements. For example, a common rule of thumb is that onsite thermal treatment is not cost effective when the volume of contaminated solids is less than 20,000 cubic yards. This breakpoint is the result of the fixed costs associated with the mobilization and demobilization of the equipment, onsite test burns, engineering, and permitting. This analysis and others must be conducted for each site to determine the thermal treatment strategy that is appropriate for use.

Thermal Desorption

Thermal desorption refers to the separation of chemical constituents that can be volatilized from nonvolatile solids, such as soil, by heating the soil to elevate the vapor pressure of the chemical so that it diffuses through and volatilizes from the solid into the gas phase. Desorption temperatures typically range between 200°F to 900°F which is much lower than the temperature required for thermally induced decomposition reactions (e.g., oxidation, pyrolysis) to occur (i.e., 1500°F to 3000°F); however, temperatures as high as 1800°F to 2000°F can be achieved in some units under a nitrogen atmosphere to preclude combustion reactions. The lower temperature units achieve removal of the VOCs and many of the PAHs. The higher temperature units also remove some of the higher molecular weight organic contaminants as well as the more volatile metals such as arsenic. At these temperatures, many of the metals that are not volatilized remain bound in the treated soil that exits the desorber. The lower temperatures and/or lack of oxygen, distinguish thermal desorption from incineration, in which combustion (destruction) of the contaminants is intended. Due to these operating conditions, the cost of thermal desorption is expected to be less than that of incineration; however, thermal desorption may not be able to effectively handle some source material such as free-phase hydrocarbons.

There are three basic thermal desorption process options for treating contaminated solids which all utilize a desorber as the initial separation step but which employ different offgas treatment systems. Each of these three options can utilize different process configurations and types of equipment for both the desorber and off-gas treatment.' The primary desorber configurations include rotary kilns and auger screws. The rotary kilns can be both direct-fired and indirect-fired. The direct-fired systems use a fuel burner as the heat source which either fires directly into the primary solid heating chamber or heats air which directly contacts the contaminated solid. The indirect-fired systems generally use a heat transfer medium such as hot combustion gas or hot oil to heat one side of a metal surface that conducts the heat to the contaminated solid. The auger configurations provide only indirect heating of the solids. The selection of the appropriate design and size of unit for each site will depend heavily upon such factors as the volume of solids that are present at the site, the soil heat content and moisture content, the nature of the contaminants, and the permitting constraints of the site, to name a few.

The three potential off-gas configurations are as follows:

- Collection of the volatilized moisture and organic contaminants using conventional condensing equipment (direct or indirect). This generally requires isolation and off-site disposal of the condensate unless it can be recycled for chemical or fuel value.. In this mode of operation, the process effectively reduces the volume of the contaminated media that requires final treatment or disposal, the recovered hydrocarbon condensates are placed into commerce, and the process may qualify for a recycle exemption under the existing regulatory framework. Such an exemption eliminates the need to obtain a RCRA Hazardous Waste Part B Permit should the untreated solid be classified as a hazardous waste.
- Incineration at 1500°F to 3000°F or catalytic oxidation followed by an air pollution control system and offgas stack.
- Discharge to the atmosphere without treatment. This would only be considered for nontoxic contaminants present at very low concentrations although normally the use of activated carbon represents a minimum treatment requirement prior to discharge.

The selection of the most appropriate process configuration depends on many factors, including site location and characteristics, regulatory and political attitudes, concentration and type of contaminants, and size and complexity of the remedial action (e.g., how much contaminated soil, what other wastes require treatment or disposal). For example, thermal desorbers have been shown to be effective for the removal of fixed cyanide from purifier box wastes. However, these materials may also contain significant quantities of sulfur since the purpose of the purifier boxes was to remove hydrogen sulfide from the manufactured gas. As such, it is likely that the desorption of the cyanides should be accomplished using indirect-fired desorption units with nitrogen atmospheres and no afterburners to ensure that sulfur dioxide is not formed. Sulfur dioxide emissions potentially pose permitting difficulties in many regions of the country and their avoidance may be required to obtain approvals for a site remediation and/or to reduce its costs.

Treated material discharged from the desorber is cooled as necessary and containerized or placed in piles until sample analysis confirms that it has met cleanup criteria. At this time, it may be possible to redeposit the treated material into the excavated area of the site. This onsite management option is reasonably straightforward above the groundwater table; however, it is somewhat more complicated below the groundwater table because the potential exists for the recontamination of the treated soil should it come into contact with contaminated groundwater or other media. This logistical issue and regulatory acceptance of placement of the treated solids must be carefully analyzed as part of any onsite management scheme.

Limited operation of onsite thermal desorption processes has occurred on MGP sites in the U.S., however, two large fixed-base facilities have been used for treating contaminated soil from MGP sites as well as other contaminated sites in the Netherlands. The units were designed, built, and operated by Ecotechniek and NBM Bodemsanering and have been operating since the early 1980s. While both companies use rotary kilns as their primary treatment unit, NBM uses an indirect-fired, co-current system whereas Ecotechniek uses a direct-fired, countercurrent system. The facilities operate their kilns at about 900° to 1100°F and their offgas afterburners at 1600° to 2900°F. Approximately 470,000 tons of contaminated soil have been treated in the NBM facility and nearly 1,430,000 tons in the Ecotechniek unit. Both units have achieved reductions of over 98% in total petroleum hydrocarbons, BTEX, PAHs, and cyanide, producing treated soil with final concentrations of less than 50 ppm, 0.2 ppm, 1.0 ppm, and 5.0 ppm respectively.

The Gas Research Institute also conducted a number of laboratory- and pilot scale studies on thermal desorption using contaminated soil from MGP sites in the United States. The results of these efforts have been summarized in three reports [GRI, 1988; GRI, 1989a; and GRI, 1989b]. For the most part, the results of these studies paralleled those of the full-scale units in the Netherlands but at somewhat lower operating temperatures and higher residence times. The GRI tests subjected the soils to temperatures of 550° to 750°F with residence times of 10 to 30 minutes and achieved reductions in total PAHs and cyanide that were similar to those achieved in the Netherlands.

Most recently, two full-scale thermal desorption systems are being installed at two MGP sites on the east coast to treat several MGP site residuals. One consists of a 10 to 15 ton per hour direct-fired rotary kiln with an offgas afterburner whereas the other is an electrically heated auger with subsequent condensation of the contaminants from the overhead gas for recovery and/or disposal. The tests are being conducted in 1993 and 1994 and the test results, in one case, will be distributed in a report that will be issued jointly by EPRI and the Niagara Mohawk Power Corporation.

Co-Burning in Utility Boilers

The co-burning of MGP site residuals in a utility boiler has evolved as a potentially viable management option. The primary advantages of using these power generating facilities is that the residuals are managed at all times under the control of the utility, the contaminants of concern are destroyed in the boiler, and the cost of the processing may be substantially less than other available management alternatives.

A recent survey of the utility industry identified four utilities that have processed several thousand tons of MGP site residuals in their boilers. In addition, three other utilities were identified who are actively pursuing this option for use in the near future. The residuals have been processed in three primary types of boilers: stokers, cyclones, and pulverized coal-fired boilers although cyclone units are preferred. The residuals have included coal- and oil-derived hydrocarbons, organic sludges, and organic-contaminated soil. These residuals were blended with the coal and comprised from one to as high as nineteen percent of the boiler feed. There were no reported problems with the boiler operation or the subsequent management of the boiler offgases or residual ashes. The processing of the residuals has occurred over only relatively short time periods and the results from longer term tests are not yet available.

In all cases, the MGP site residuals were classified as non-hazardous at the point it was placed in the boiler. This is important since the processing of hazardous wastes at the utility would result in extensive permitting requirements associated with the treatment, storage, and disposal of hazardous wastes. However, it is noteworthy that the Edison Electric Institute recently developed a guidance document in conjunction with the U.S. EPA for the purpose of facilitating the management of MGP site residuals in a utility boiler by treating any "characteristic hazardous" residuals in nonpermitted 90-day accumulation units[*] to render it nonhazardous prior to leaving the remediation site. Acceptable treatment includes, among other activities, screening and/or crushing operations as well as blending with amendments (e.g., sawdust or coal). If this incidental treatment occurs within 90 days of generation, no permitting of the treatment process is required. While the U.S. EPA endorsed this management approach, utilities will need to determine whether state/local laws and regulations also allow the use of 90-day accumulation units to treat hazardous MGP site residuals onsite without a permit.

Each utility will have to conduct site-by-site reviews of their boiler systems to determine the viability of this management option for their MGP site residuals. While it appears-from the available information that this option can be successful under many circumstances and has been approved by EPA as an environmentally protective strategy, there are some environmental and non-environmental considerations that will

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[*] Three units are eligible as 90-day accumulation units under the current regulations. These units include tanks meeting the standards of 40 CFR Part 265 (Subpart J), containers meeting the standards of 40 CFR Part 265 (Subpart I), and a containment building. The latter generally consists of a concrete pad or a similar floor inside a building (Edison Electric Institute, 1993).

enter into the ability to implement such a management strategy on a full-scale basis. Some of the more important of these considerations are:

- material handling requirements and logistics associated with the residuals:

  The utility must determine if additional material processing equipment, including crushing and screening, will be required at .the power plant or if, these operations will be conducted separately at each individual MGP site. It must also be determined if the truck or rail unloading facilities at the plant are capable of handling non-uniform mixtures of solids that may contain non-crushable debris or stone.

- storage of residuals at the power plant and management of associated fugitive emissions:

Separate storage of the residuals may require the construction of a covered storage pad or a lined storage area with segregated stormwater management system. The stormwater management system may include special treatment units and will most likely require individual discharge permits.

- impact of the residuals on the power generation capacity of the facility and the lifetime of the. equipment:

  The potential derating of the power generation capacity of the facility should be examined along with potential decrease in the lifetime of the facility equipment that could result from enhanced corrosion, erosion, or other unusual processing conditions.

- impact of the residuals on the facility discharges including both stack gas emissions and boiler ash:

  Modifications to the environmental management. systems and permits may be required due to the changes in the feed stock to the power plant. Examples of the types of issues are potential increases in sulfur dioxide emissions resulting from the combustion of spent purifier box wastes or the change in the bottom .ash characteristics such as slagging temperature.

- reactions of the local community:

  The utility should inform the local community of the plans to combust contaminated MGP site residuals in the utility boiler. This should be done as part of a community relations plan that is designed to present the technical facts of 'the project and to answer the questions and solicit the input of the local public.

Each power plant will have an individual set of constraints and requirements against which it should evaluate the above factors to determine the feasibility of this management option for MGP site residuals. This effort will require close coordination with the power plant operating personnel, the governing environmental regulatory agencies, and the public-at-large.

Incineration

Incineration refers to the high temperature oxidation of residuals. The basic incinerator components normally include a primary and secondary combustion chamber followed by an air pollution control system. The residuals are fed to the primary chamber which typically operates at 1000°F to 2000°F where the contaminants are volatilized into the gas phase and either pyrolized (in starved air environments) or oxidized (in the presence of air) to simple combustion products such as CO_2, H_2O, HCl, and SO_2. Nitrogen containing compounds (i.e., NO_x) may also be formed. Liquid wastes can be incinerated completely within a single high temperature combustion chamber. For most solids, a higher temperature secondary combustion chamber (SCC) which typically operates at between 1800°F and 2200°F is usually required after the primary chamber to assure complete destruction of all volatilized contaminants that might carry over from the primary combustion chamber.

For the most part, offsite incineration is mainly suited for the low volume residuals that are present at an MGP site such as pumpable or non-pumpable free-phase hydrocarbons or purifier box wastes. 'This limitation is driven primarily by costs which are attributed to shipping and packaging requirements, distance to the facility, and the cost of treatment. The type of waste that a commercial incinerator can handle depends upon the type of incineration equipment, the requirements of the facility air permits, the hazardous waste classification of the material, and the nature of the contaminants of concern. A list of commercial incinerators that have been permitted by the U.S. EPA as of 1989 are given in Table A-5 in Appendix A. The combustion of most of the MGP site residuals in these units should not be a problem although it is likely that trace metals, cyanide, and sulfur content of these materials will be closely scrutinized. This may result in the imposition of surcharges or possible rejection of the purifier box wastes since they may contain elevated concentrations of the inorganic and heavy metal contaminants.

Incineration can be achieved using both mobile transportable and fixed-base units. The fixed-base systems are located at offsite facilities and typically consist of large, rotary kilns ranging in size from 80 to 100 MM BTU/Hr and with solid capacities of 20 tons per hour or greater. The mobile/transportable units consist primarily of:

- rotary kilns
    - Small: < 20MM BTU/Hr, 1-2 Tons/Hr;
    - Medium: 20 to 40 MM Btu/Hr, 4-7 Tons/Hr; and

  - Large: > 40 MM Btu/Hr, >10 Tons/Hr.
- infrared conveyor furnaces: 5-7 Tons/hr; and
- fluidized bed combustors: 4 Tons/hr.

Both the fixed and mobile/transportable systems are currently available for full-scale application to MGP site soils. A recent publication identified 13 companies within the United States that offer these services and that have full-scale remediation experience on source material and contaminated media [Cudahy, 1989].

The advantage of incineration is that it can reduce the concentrations of all organic contaminants to very low levels in the solid matrices. Furthermore, it destroys the contaminants, converting them to carbon dioxide and water. This feature makes it a very attractive treatment technology of solid matrices that contain organic contaminants with a wide spectrum of chemical and physical properties. However, the presence of selected inorganic compounds, such as sulfur and nitrogen, and selected heavy metals can yield emissions in the incinerator offgas or leachates from the incinerator ash that may not be acceptable to the regulatory agencies or the public. While these emissions and discharges can be adequately controlled, the permitting process for onsite treatment units can be prohibitive both in terms of time and money. This is especially true for MGP sites that are located in urban or residential settings. As such, it is often more expedient to utilize offsite incineration facilities which are fully permitted than to seek to permit an onsite unit. The penalty associated with this choice is the cost of transportation and the potentially high processing fees at the facility.

Final ash disposal represents another confounding factor for onsite incineration of soil. If the placement of the treated soil, or "ash," cannot occur on the site itself, it is unlikely that onsite thermal treatment will be economical. This is the result of the simple observation that the soil may consist of as much as 98 to 99% inert material. As such, the effectiveness of achieving a soil volume reduction of 1 to 2% using onsite thermal treatment prior to its offsite shipment will not be sufficient to economically justify its use.

5.2.2 RECYCLE/REUSE

There are several *ex situ* management options that involve the recycle of contaminated materials into manufactured products. The specific products of interest include cold- and hot-mix asphalt, brick and cement.

Bituminous Concrete (Asphalt)

Bituminous concrete consists of a mixture of sand and aggregate (90% to 95% by weight) and a liquid hydrocarbon (5% to 10% by weight). The liquid hydrocarbon that is most often used is a bituminous material known as asphalt that is derived from the distillation of petroleum and that consists of, among other chemicals, aliphatic, mononuclear, and polynuclear aromatic hydrocarbons. Over time, asphalt has become the common term for bituminous concrete and this nomenclature is used throughout the remainder of this report.

It is proposed that hydrocarbons and/or contaminated soils from MGP sites that contain primarily mononuclear and polynuclear aromatic hydrocarbons may be incorporated into the asphalt production process and partially replace the liquid hydrocarbon and/or the aggregate of the mixture. Following incorporation into the mixture, it is expected that the hydrocarbons and/or soils will be bound both chemically and physically into the asphalt product. There are two asphalt products which can be produced from organic-contaminated soils and liquid hydrocarbons: cold- and hot-mix asphalt. The hot-mix asphalt is produced by mixing hot aggregate with melted asphalt at 500° F. In contrast, cold-mix asphalt is produced by mixing aggregate at room temperature with an asphalt-water emulsion. The hot-mix asphalt is considered a higher-grade product and is generally used for surface paving of roadways. Most hot-mix asphalt plants are fixed facilities and the raw materials must be shipped to the facilities for processing. On the other hand, the raw material requirements of the cold-mix asphalt are less stringent, e.g., a soil with a broader grain size distribution can be used, and may be more amenable to the use of contaminated soils. Cold-mix asphalt can easily be produced onsite and typical uses for the cold-mix asphalt are as a sub-base for primary and secondary roads and parking areas.

The production of asphalt from contaminated soils of MGP sites has been done on both a laboratory and field-scale basis. As part of the hot-mix asphalt process, the contaminated materials are heated and effectively decontaminated in a thermal desorber prior to their combination with the liquid hydrocarbon. This is not the case for the cold-mix asphalt which simply mixes the contaminated material, as is, with the hydrocarbon/water emulsion. The primary specification of concern with both products is the strength requirement. Typically, the strength is correlated to the soil particle size and the strength specification is translated to a particle size limitation for the aggregate that is used. This has the effect of limiting this recycle option to contaminated soils that are predominantly gravel and sand and that contain little silts and clays. However, if the strength specification is in the form of a performance specification for the product (e.g., Marshall Compressive Strength), the particle size constraints on the feedstock will be much less severe since data exist which indicate that a significant fraction of fines can be tolerated in the asphalt product without compromising its strength characteristics.

An additional concern regarding cold-mix asphalt is the potential for the leaching of contaminants from the asphalt product. This concern is based on the fact that, unlike hot-mix asphalt, the contaminated soils are not preprocessed prior to incorporation into the asphalt. As such, the contaminants may not be physically or chemically bound into the product and may be leached from the product by infiltrating water. Standardized leach tests to experimentally examine the leaching of contaminants from asphalt products are not currently available. As such, there are insufficient data available to make an adequate technical evaluation of the characteristics of the leachate from an asphalt product that is prepared from MGP site residuals and to compare that leachate with those from an asphalt product that is made from clean aggregate. Furthermore, it should be recognized that the environmental impact of any leachate from an asphalt product is extremely site-specific and will depend upon a number of factors such as the volume of annual rainfall, the regional temperature cycles, and the characteristics of the subsurface geologic materials, to name a few. The full-scale application of the recycle of MGP site residuals in cold-mix asphalt will most likely require some type of leach evaluation and utilities should be prepared to include such an evaluation as part of their feasibility analysis of this approach to soil remediation.

Several utilities have had contaminated soils from MGP sites processed into hot-mix asphalt. One northeast utility sent 12,000 tons of contaminated soil to a facility in South Carolina which thermally desorbed the soil prior to selling it to a hot-mix asphalt production facility. In addition, a hot-mix asphalt production facility in Georgia has processed 25,000 to 30,000 tons of organic-contaminated soils from MGP sites and a facility in Wisconsin conducted a test to produce 50 tons of hot-mix asphalt. The asphalt product in Wisconsin was used as pavement at an operating power generating facility. More recently, a northeast utility produced 400 tons of cold-mix asphalt from contaminated soils as part of an onsite demonstration test and now plans to subject the product to both strength and leach tests in the field. As part of the test, an asphalt product was also produced using clean aggregate and this will be tested to serve as a control for the evaluation of the asphalt that was produced from the contaminated soft.

Brick Manufacture

The recycle of MGP site residuals into the manufacture of bricks has also been examined. Bricks are produced from a "mud" that consists of powdered shale, firing clay, sawdust, and water. This mud is forced into brick molds which are dried at 100 to 600°F and then fired in a kiln. One such kiln is the tunnel-kiln which consists of three sections: brick heating zone (ambient to 1000°F), the burner or high temperature section (1000°F to 1500°F), and the brick cooling zone (1500°F to 350°F). The high temperature or center section of the kiln is fitted with a natural gas burner which provides the heat for the process. The bricks travel through the tunnel-kiln on a raft car that moves countercurrent to a flow of combustion gases and air. The combustion gases from the center, high-temperature section of the kiln, pass-countercurrent to the incoming bricks and are cooled from 1800° to 300°F while the bricks are simultaneously heated. The incoming air enters the kiln at the discharge end for the bricks and is heated from ambient temperatures to 1000°F before entering the center, high temperature zone of the kiln. In this zone, the bricks are cooled by the incoming air. The air and the burner exhaust exit the kiln at the entry point for the bricks.

The primary environmental concerns with the manufacture of the bricks are the offgases from the drying step and the kiln itself. The contaminants of concern that are in the offgases during normal operation are particulates; however, the emission of VOCs, PAHs, and cyanide may be a concern during the processing of MGP site residuals. The primary residuals that are candidates for use in brick manufacture are purifier box wastes (as a substitute for the sawdust) and contaminated soil and sediment (as substitutes for the shale and clay). It is interesting to note that the brick manufacturing process prefers soils with more clays and silts which is very complementary to the needs of the asphalt production facilities which require more sands and gravels.

Tests have been conducted at. the Richland Brick manufacturing facility in Richland, Ohio, which produced brick from organic-contaminated soils from an MGP site. The test was monitored by the Ohio Environmental Protection Agency and a permit was issued to the facility for the processing of these materials. In addition, another brick manufacturing facility in the southeast has plans to conduct a similar test to obtain modifications to their permits for the processing of MGP site residuals.

Cement Manufacture

Portland cement is made by heating a mixture of calcium, aluminum, and iron (in the form of limestone, sand, and clay) in a high temperature furnace or kiln. The feed is fed into an elevated end of a rotary kiln where it is heated to 1500°F to evaporate all of the water. The material can be fed either in a slurry form or as a dry feed. The feed then slowly moves by gravity toward the lower, higher-temperature zones of the kiln where the material eventually forms a clinker. Typically, the solid material temperatures exceed 2700°F in the sintering zone and the flame temperature exceeds 3500°F, similar to temperatures in the rotary kiln incinerator. The clinker is discharged from the kiln and cooled, after which it is mixed with gypsum and ground to make Portland cement. Portland cement is used to make concrete by mixing it with water and gravel. The offgas from the kiln travels through a dust collector prior to its discharge to the atmosphere.

In recent years, cement production facilities have begun to manage various wastes and residuals in their facilities. More than one-fourth of the 100 cement kilns operating in the United States are permitted to use hazardous wastes as fuel- for manufacturing Portland cement. In fact, in 1991, cement kilns burned 1.3 million tons of hazardous waste-derived fuels according to the Cement Kiln Recycling Coalition in Washington, DC. In addition to the hazardous waste-derived fuels, many kilns will also accept non-hazardous soil. The high-BTU hazardous wastes are used to replace or supplement the traditional fossil fuels used in this energy-intensive process while the contaminated soil contributes sand and other geologic materials to the formation of the clinker. However, cement kilns are limited as to the types and amounts of hazardous wastes they can use and still preserve the quality of their products. It should be noted that the EEI MGP Combustion Strategy with its use of 90-day accumulation units may also be applicable to treat characteristically hazardous MGP site residuals and render them non-hazardous before combustion in a cement kiln.

The requirements of the cement kiln provide an outlet for any MGP site residuals that can provide energy or calcium, aluminum, or iron to the operation. As such, pumpable liquid hydrocarbons, purifier box wastes, and contaminated soil and sediment may all be candidates for this form of management. It should be noted that the purifier box wastes are generally high in both iron and energy content. Also, many of the soils may also contain high iron and limestone. Finally, the cement kiln would be capable of accepting soils with a significant portion of silts and clays providing these materials do not result in excessive contributions to the particulate emissions from the kiln stack. Other limitations on the waste-derived fuels are usually related to the heat content and the concentrations of moisture, solids, chlorine, and selected metals. The specifications for these parameters are usually part of the RCRA permit for each facility. An additional concern regarding contaminated soils is the emission of volatiles in the kiln stack. The VOCs will be rapidly volatilized from the soil as it enters the kiln and there will be little or no opportunity for the destruction of these organic compounds prior to their discharge to the atmosphere. To the extent that volatile emissions are a problem, it may be necessary to utilize low temperature thermal desorbers to pre-process the soils prior to their injection into the cement kiln. The offgases from the desorber can then be injected into the hot zone of the cement kiln to provide sufficient residence time and temperatures achieve their complete destruction prior to release to the atmosphere.

Several utilities have investigated the use of cement kilns for the management of their MGP site residuals. In one case, approximately 50 tons of organic-contaminated soil were sent to a cement kiln in Heartland, Kansas, as part of a test burn trial. However, the use of cement kilns on a large-scale basis for MGP site residuals has not yet developed.

5.2.3 SOIL AERATION

Aeration of contaminated soil and/or sediment provides a means for the removal of VOCs and volatile inorganic compounds from the solid matrix. This treatment technology is usually combined with other technologies that are capable of treating the non-volatile contaminants such as the PAHs. For example, one alternative is to pretreat contaminated soil using aeration prior to its incorporation into cold-mix asphalt. This pretreatment step would eliminate from the solid those contaminants (e.g., naphthalene) whose leaching from the asphalt may be an environmental concern. This treatment would be effective since the VOCs are also the most soluble in water. Similarly, any other process treatments that would benefit from the removal of the VOCs could be preceded by soil aeration.

A typical soil aeration treatment system requires the excavation of the soils and its placement in piles that are four to five feet high. Within the pile is an air distribution system that consists of parallel slotted PVC pipes which are capped at one end. Forced-air systems use an air blower to move fresh air through the pipes and into the soil pile. Air that contains the VOCs is forced from the pile and released to the atmosphere. However, should the release of the contaminants into the atmosphere be a problem, the air movement can be reversed by applying a vacuum to the perforated pipes. This draws fresh air into the pile and discharges it as a point source from the vacuum pump. This point source can be directed to a vapor phase treatment system to eliminate any air emissions from the system. Alternatively, aeration could be achieved during the routine management of the solids at the site; however, the efficiency of this removal would be substantially less than the managed aeration piles.

The effectiveness of the soil aeration will depend upon a number of process variables. The most important of these include the air temperature, the volumetric air flow rate, the moisture content of the soil, the contaminant concentrations in the soil, and the chemical and physical properties of the contaminants.

5.2.4 BIOLOGICAL TREATMENT.

Biological treatment involves the conversion of contaminants into biomass and harmless byproducts of microbial metabolism such as carbon dioxide, methane, and inorganic salts. It is an attractive form of treatment because it provides the opportunity to achieve "destruction" of the contaminants at a relatively low cost. However, like most remediation technologies, it is not applicable to all wastes under all conditions and a case-by-case evaluation is required to determine its applicability at a specific site.

An extensive research effort has been focused on the biological treatment of organic-contaminated soils from MGP sites. This effort has been led by GRI [Gas Research Institute, 1992] although other organizations such as EPRI, the U.S. EPA, the U.S. Department of Energy, and individual utilities have also provided significant contributions to it. The results of these efforts have revealed that the level of reduction that is achieved for contaminated soils using biological treatment systems is quite variable and is largely dependent upon the characteristics of the soil-contaminant matrix. This observation is attributed to the fact that the contaminant reduction is dictated by the mass transfer of the contaminant from the soil into the aqueous phase and not by the kinetics of the aqueous phase biological reactions. Stated differently, the lack of biological treatment of a specific contaminant in the soil is not due to its resistance to biological reactions; rather it is due to its inability to enter the aqueous phase where the biological reactions occur. Since each soil-contaminant combination exhibits unique mass transfer characteristics, which are a function of the chemical and physical properties of the contaminant and the geologic materials in the soil, the achievable treatment endpoint is also somewhat unique. For this reason, waste-specific treatability and/or field studies are necessary to define the optimal treatment conditions for biological treatment and the treatment endpoints that are attainable when biological treatment is applied to a specific site.

It is also true that the current research has demonstrated that the organic contaminants that do leach from the soil, i.e., those that are readily transferred from the soil to the aqueous phase, are also readily biodegraded. Consequently, following biological treatment, the contaminants that are mobile in the environment have been treated and those that remain in the soil are bound so tightly into the soil matrix that they can be considered immobile. In effect, the contaminated soil has been "biostabilized" and may no longer represent a risk to either environmental or human receptors. This concept is extremely important if the potential to use biological treatment for the remediation of contaminated soil from MGP sites is to be maintained. For example, biological treatment will never be capable of attaining the level of contaminant reductions that are achieved using incineration or other thermal treatment technologies and it will likely require longer time periods to achieve its maximum extent of treatment. However, if it can be argued that the biological treatment endpoints are still protective of the environment and of human health, this method of treatment may be acceptable to the regulatory agencies at a significantly less cost than thermal treatment. This risk-based approach to remediation is gaining momentum as the United States looks for better means to prioritize its manpower and financial resources associated with the management of the environment and is critical to the future use of bioremediation for the management of MGP site residuals.

Prepared-Bed Treatment

Prepared-bed treatment is an engineered process that involves the controlled application of a residual material (i.e., contaminated soil, sediment, or purifier box wastes) onto a prepared soil surface and the incorporation of the residual into the upper soil zone. The technology is generally used onsite with the residuals mixed above-ground and then applied to a designated treatment area. This process is one of the older and most widely used technologies for the treatment of organic contaminants in soil. In particular, the technology has been used successfully throughout the United States, especially at petroleum refinery sites treated under RCRA, and also with creosote contaminated soil and sludges.

Prepared-bed treatment is not the indiscriminate dumping of residues on land, and it is not landfilling. A treatment site is designed and operated to: (1) maximize residue degradation and immobilization, (2) minimize release of dust and volatile compounds, as well as percolation of water soluble compounds, and (3) control surface water run-on and run-off. Prepared-bed treatment generally occurs in an aerobic soil mixture, approximately 0.5 to 1.0 feet deep, that is managed to promote the growth of indigenous microorganisms to biodegrade contaminants and to promote immobilization of contaminants. The residuals can be handled in a variety of manners to minimize odors and provide good distribution by plowing, disc harrowing, or other similar methods. More highly contaminated materials may require blending with less contaminated materials depending upon the type and concentration of contamination. Mixing also provides aeration of the soil which enhances biological activity. In some cases, nutrients or fertilizer may be required to maintain the proper microbial environment and lime may be needed periodically for pH control.

The foundation of a prepared-bed treatment unit can be either an impermeable liner (plastic or clay) or a prepared packed ground surface. Both are designed to insure minimal downward migration of contaminants. For a prepared ground surface, the soil bed is designed to reduce or eliminate downward percolation of excess water to the underlying groundwater by enhancing run-off which is collected and recycled as irrigation water. The unit is designed to prevent precipitation run-on so that water moving through and around it can be controlled. The size of a unit can range from a quarter of an acre to ten acres or more. The system is engineered for the specific site situation taking into account available land area, the amount of material to be treated, the desired treatment level, and the time frame available for treatment.

The viability of land treatment rests on its capability to reduce or immobilize the concentrations of soil contaminants to acceptable levels, through biological and chemical transformations, along with controlling emissions (i.e., volatilization and leaching) of organic contaminants from the treatment unit to below levels that could cause public health or environmental concern. It is generally observed that the more desorbable and more water soluble compounds are biodegraded at a faster rate and to a greater extent than the less desorbable and less soluble compounds. In addition, studies have shown that bioremediation of soils is capable of detoxifying and immobilizing soil contaminants to where they no longer represent a source of volatile emissions or contaminated leachate.

Composting

Composting is a biological process historically used to treat wastes with high concentrations of biodegradable organic solids (e.g., dead vegetation). From an industrial-based perspective, composting is an emerging technology used to treat organically contaminated soil, sediment, and purifier wastes. This type of treatment consists of piling the contaminated material, sometimes mixed with a bulking agent, at heights of three to six feet. The addition of bulking agents increases the total volume of the material to be treated and facilitates mixing requirements and oxygen transfer. (It is anticipated that purifier box wastes can serve as the bulking agent if composting is applied to MGP site residuals). Aeration is provided by either. forcing air through a contained system (soil heap composting) or by mechanically turning over the soil which also serves to mix the material (windrow composting).

These systems are amenable to moisture, pH, and nutrient control by simple irrigation techniques, and to volatile emission control when the system is covered. This ability to control volatile emissions is a distinct advantage of composting over prepared-bed treatment. When temperature is critical to increasing removal rates, the compost pile can be amended with other sources of organic matter to increase biological activity and the temperature of the system, or it can be covered or enclosed for better process and temperature control. Reduction of contaminants is achieved until the particular compounds no longer desorb from the material. At this point, the material no longer represents a leachate source and can be considered biostabilized; however; the contaminant concentrations may not be sufficiently low to meet a specific treatment endpoint. If this is the case, the success of the treatment will depend upon the ability to negotiate an alternative treatment endpoint with the environmental regulatory agencies.

Liquid/Solid Bioslurry Treatment

The liquid/solids bioslurry reactor is a modified version of the activated sludge process used for the treatment of solid matrices such as soils. An aqueous slurry, created by combining contaminated material with water, is fed to a bioreactor and aerated. The principal objective of aeration is to supply sufficient oxygen throughout the slurry to promote aerobic microbial activity that will degrade the organic contaminants in the soil. The liquid/solids bioslurry reactor is operated to maximize mass transfer rates and contact between contaminants and microorganisms. Biodegradation is achieved in a liquid/solid bioslurry reactor when the hydrocarbons that migrate to the aqueous phase are degraded (mineralized) to carbon dioxide and water.

The following five generic elements are common to most liquid/solid bioslurry reactor processes:

- Pretreatment (if necessary);
- Creation of an aqueous slurry with mechanical agitation;
- Aeration and addition of nutrients and microorganisms;
- Dewatering; and
- Post treatment (if necessary) and ultimate disposal.

Pretreatment, post-treatment and ultimate disposal methods utilize standard equipment and techniques. For example, pretreatment may require the sizing and classification of the solids to provide an optimal particle size distribution for the treatment system. Post-treatment may include fixation of the treated material which could be followed by onsite placement. Process designs of liquid/solid bioslurry reactor systems vary in the hardware design, process operation and the sequence in which these steps are performed. The liquid/solid bioslurry reactors can be operated in series or in parallel. Operating specifics such as reactor volume and solid residence time are highly waste specific.

Potential dewatering steps include gravity separation, conventional drying beds, centrifugation, stabilization or bulking, thermal drying, and vacuum filtration. Alternatively, the treated soil/water slurry can be directly applied to a prepared-bed treatment area for further treatment with no specific dewatering step needed provided that the hydraulic loading to the prepared-bed treatment area does not exceed the field capacity of the soil.

As with prepared-bed treatment, the more desorbable and more water soluble compounds are biodegraded at a faster rate and. to a greater extent than the less desorbable and less soluble compounds. For soils containing less than 10 percent silts and clays (defined by passing a No. 200 U.S. Standard Sieve), the extent of contaminant soil reduction via liquid/solids bioslurry reactor treatment and prepared-bed treatment are statistically similar. However, the rate of contaminant reduction in a slurry reactor is much faster than that in a prepared-bed treatment unit. For soils containing greater than 10 percent silts and clays, both the rate and extent of contaminant reduction are greater in liquid/solid bioslurry reactor.

5.2.5 AQUEOUS/SOLVENT EXTRACTION

Aqueous/solvent extraction technologies separate contaminants from solids using physical mechanisms including washing, flushing, dissolution, or leaching. Extraction technologies generally target treatment of soil or sediment but may be applicable to residues or debris, depending on the characteristics of these materials and the capabilities of the technology and associated equipment.

Extraction technologies generally employ some method of contacting the contaminated solid with either water or a hydro-carbon solvent. This contact step results in a physical separation that transfers the contaminants from the solid material into the liquid medium or extractant. After contact with the solid material, the extractant is treated for removal of the contaminants and then recycled for additional solid extraction cycles. The solids generally retain some fraction of the extractant. This is removed by additional washes using clean solvents or by other physical/chemical means such as heating or air stripping.

For the most part, processes which utilize non-aqueous solvents have not received wide-spread application. These processes require extensive facilities to manage the hydrocarbon solvents, considering both safety and environmental factors, and often involve elevated temperatures and pressures. Lastly, the number of unit operations tends to escalate rapidly as successive cycles of solvent/solid contact are required and separations of the residual solvent from the solids and the multiple-phase liquid extracts are required. As such, aqueous-based extraction processes are more common simply because of the ease of handling water as compared to hydrocarbon solvents. However, the aqueous processes also lead to the generation of byproduct solid or liquid streams which must be subjected to further treatment. As such, they can also be plagued by the need for multiple unit operations and increasing complexity. Furthermore, aqueous-based systems are limited by the same mass transfer constraints as were mentioned for biological treatment. Consequently, they will most likely not achieve treatment endpoints that are as low as solvent-based systems.

Two approaches to aqueous-based extraction of soils both involve the biological treatment of the contaminants after they enter the aqueous phase. The one approach, liquid/solids bioslurry reactor, was discussed previously and involves the biological treatment of the aqueous phase in a single reactor as it remains in contact with the solids. The other approach biologically treats the aqueous phase following its separation from the solids. In both cases, the dewatering of the solids must occur and subsequent treatment of the solids may be required. Lastly, it has been well documented that most organic-contamination in soils or sediments is concentrated in the fine fraction (i.e, less than No. 200 U.S. Standard Sieve). To take full advantage of this observation, the aqueous-based extraction processes are often preceded by a size classification following the initial extraction step. In this manner, the mass fraction of the soil which has been sufficiently treated after this initial step need not be subjected to additional treatment. This volume reduction can be substantial and has the potential to have a significant impact on the costs of treatment.

EPRI has contributed to the development of another aqueous-based extraction process which involves solely physical processes. The process uses coal as an adsorbent and scouring agent to remove the hydrocarbons from the contaminated soil. The coal is mixed with the contaminated soil in a hot water slurry and fed to a tumbler reactor. The products are a coal-tar fuel, the treated solid, and an aqueous liquid. The process has been tested on a lab and pilot scale [EPRI, 1992] and future field tests are planned to demonstrate the full-scale application of this technology to MGP site residuals.

5.2.6 CHEMICAL TREATMENT

Chemical treatment encompasses a range of technologies that result in the chemical decomposition of contaminants. The chemical reactions are induced by adding chemical reactants such as oxidizing agents, elevating temperatures and pressure, or introducing electrical or electromagnetic energy. (It should be noted that chemical reactions also may take place during certain stabilization processes. These reactions are not included as part of this discussion).

Chemical destruction of contaminants can serve different remedial purposes. For example, the contaminants can be eliminated or completely destroyed or converted to contaminants which are less hazardous or toxic to the environment. Alternatively, the chemical treatment can also convert the contaminants to other species that are more amenable to treatment by other applicable and cost effective technologies such as biological treatment.

Almost exclusively, chemical treatment technologies rely on aqueous-phase chemistry, which requires the dissolution of the contaminant and reactant species into water. As such, the contaminants must be transferred from the solid phase matrix into the aqueous phase prior to treatment. Under these circumstances, mass transfer of the contaminant into the aqueous phase through solubilization, desorption, or diffusion is often the rate-limiting step in the treatment process, just as it is for biological treatment and aqueous-based extraction systems. Furthermore, the mass transfer of the chemical reactant into the aqueous phase is also important to chemical destruction processes. The proper dissolution and distribution of the reactants and contaminants requires extensive mixing which for aqueous slurries or soils represents a major design and operational issue. It should be noted that mass transfer limitations may be overcome by chemical treatment systems if the chemical reactions can occur directly with the contaminant in the soil matrix. Under these conditions, the chemical characteristics of the soil contaminants can be altered thereby improving the ability to transfer them into the aqueous phase. Some chemical reactants also have the ability to affect the soil properties, e.g., dissociate soil aggregates, which may also improve the mass transfer characteristics beyond the simple aqueous-based system. However, there are little data to document these phenomena and to support the use of chemicals for the treatment of contaminated soils.

As noted, the experience in applying any of the chemical treatment technologies directly to contaminated solids is very limited. Typically, the determination of feasibility is based upon engineering judgment that considers the following factors:

- Reaction interferences caused by soil contaminants;
- Mass transfer of reactants to the contaminants;
- Ability to create, control, and maintain necessary reaction conditions such as temperature and pH; and
- Risk potential during and after treatment.

The one application which has been investigated in the laboratory and is now moving into a field demonstration test is a combined chemical/biological treatment process.

This process involves the addition of Fenton's Reagent to a liquid/solid bioslurry reactor. Fenton's Reagent is a mixture of hydrogen peroxide and ferrous sulfate. The purpose of adding the reagent is to chemically convert the insoluble or biologically recalcitrant contaminants to other species which are more amenable to dissolution in water and/or biological treatment. Ultimately, the process will be optimized to employ the minimal amount of chemical addition that is necessary to assist the complete biological treatment of the contaminated matrix.

It should be noted that since the application of chemical treatment processes requires an aqueous extraction of the contaminants, many of the advantages and disadvantages of the soil extraction technologies apply to this treatment approach. The most significant disadvantage is the tendency for the treatment to require multiple process steps that dictate substantial handling of the solids.

5.2.7 STABILIZATION/LANDFILL

Stabilization refers to the process by which contaminant mobility is decreased through physical and/or chemical means. "Stabilization" has been used synonymously with a variety of terms including immobilization, encapsulation, fixation, and solidification. Specific definitions have been assigned to each of these terms by the U.S. Environmental Protection Agency and others to differentiate between the fundamental physical and chemical processes that take place. For the purposes of this document, stabilization is used generically to refer to all such technologies and processes.

Ex situ stabilization deals with the excavation and subsequent partial or full immobilization of the contaminants. Excavation and partial immobilization is useful for improving waste handling characteristics and solidifying liquid wastes prior to disposal in a secure landfill. Excavation and full immobilization is generally used to convert residuals to a solid mass with more complete immobilization of soluble contaminants. The equipment required for *ex situ* treatment typically includes standard cement mixing and handling equipment, however specialized and proprietary equipment may be used. Typical stabilizing agents include portland cement, cement kiln dust, lime kiln dust, fly ash, soluble. silicates, and epoxy and polyester resins. Some commercial companies have their own proprietary mixtures which are usually some combination of these agents. Once the stabilizing agent is added, setting and curing time can take up to several days or longer.

The stabilization process can be performed on-site or at off-site facilities. Since the equipment is quite mobile, the on-site treatment can be conducted with relative ease. On-site treatment would require space for the equipment and a Staging area for curing the stabilized material.

The performance of stabilization processes has traditionally been determined by measuring the concentration of EPA designated contaminants in an aqueous extract of a treated sample. However, there is general concern that the EPA tests, which require that the sample be crushed prior to extraction, is not representative of the actual situation of a monolith that is placed within a landfill. Nevertheless, vendors have reported leachate concentrations of contaminants as low as EPA drinking water standards for a variety of wastes and stabilizing formulations. Organic-contaminated solids have been stabilized to the extent that there have been significant reductionism the contaminants that leach from the waste. In addition, the performance of this technology, as determined by achieving a solid material (no free liquid) with characteristics suitable for placement in a landfill, has been demonstrated on both inorganic and organic-contaminated solids. However, performance is very waste dependent and formulations to successfully stabilize organics are very specialized. Lastly, performance as measured by long term stability of the contaminants in a landfill environment has not been well documented.

6

IN SITU MANAGEMENT OPTIONS

Contaminated soft, sediment, and groundwater at MGP sites can be managed using a variety of *in situ* techniques. These techniques can be grouped into two categories: containment and treatment. The containment techniques are well-established and have been used extensively in both environmental and non-environmental settings. While containment does not destroy the contaminants, it has been demonstrated to be effective in preventing or retarding' the migration of contaminants to environmental or human receptors and in achieving rapid and significant reductions in overall risk. On the other hand, the *in situ* treatment techniques destroy the contaminants thereby eliminating the potential for the eventual escape of contaminants from the site. But this form of treatment is not as well established as *ex situ* .forms of treatment because it can be more difficult to implement and to monitor its effectiveness. The problems with implementation are attributed primarily to the difficulty with delivering the necessary reactants to the. subsurface environment in a uniform and consistent manner. Similarly, problems with measuring treatment performance are due to the heterogeneity of the subsurface geologic environment which makes it difficult to be certain that uniform treatment has occurred.

In spite of the implementation issues associated with *in situ* management of the contaminated media, its use at MGP sites is often required because the physical setting of the site or the location of the contamination makes *ex situ* treatment technically impractical or prohibitively expensive. Furthermore, this approach also eliminates the risk and cost associated with the removal of the contaminated media .as well as the final disposition of the treated material.

The remainder of this section describes the primary *in situ* management techniques that may be applicable to the contaminated media at MGP sites. Because of the interactive nature of contaminated media (i.e., soil and groundwater) in the subsurface, no attempt has been made to distinguish between their treatment or containment at a site. Rather, .the emphasis has been placed on containment versus treatment technologies and their applications in the saturated and unsaturated (vadose) zones of the subsurface. The focus is also on those techniques that can be immediately applied commercially to the sites. However, it should be noted at this time that even though commercial applications are feasible, the uncertainty associated with subsurface treatment of contamination often leads to extended periods of remediation that are accompanied by extensive monitoring requirements. These factors can often raise the cost of this approach and may justify the reconsideration of *ex situ* treatment options.

6.1 IDENTIFICATION AND EVALUATION OF OPTIONS

Figure 6-1 presents the *in situ* management options for contaminated media at MGP sites. The options include both containment and treatment management techniques. Containment techniques encompass physical barriers as well as hydraulic control. Treatment techniques have been segregated based upon the saturated and unsaturated (or vadose) zones of the subsurface and include stabilization, flushing or extraction, .chemical oxidation, and biological treatment.

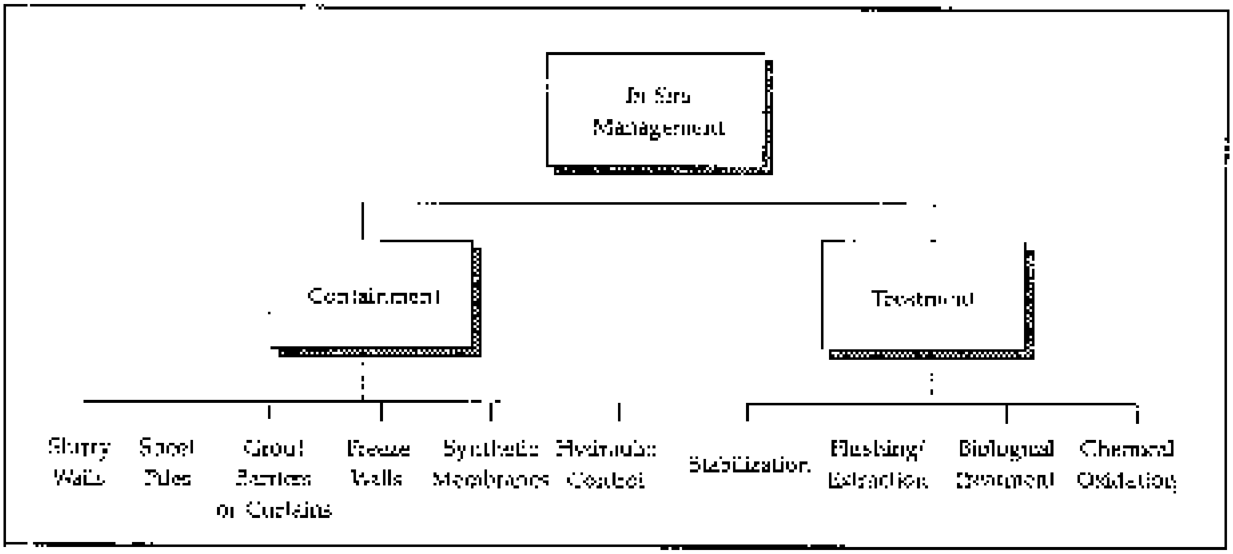

Figure 6-1. ***In Situ*** **Management Strategies for Contaminated Media at MGP Sites.**

6.1.1 CONTAINMENT

Containment management options are designed to prevent the subsurface migration of the contaminants from the site. The primary mechanisms for contaminant migration are the movement of non-aqueous phase liquids (NAPLs) and the movement of groundwater that contains dissolved contaminants which have leached from NAPLs and contaminated soil. As such, the containment management options include physical barriers and hydraulic controls that will intercept the flow of NAPLs and groundwaters prior to their offsite movement.

Physical barriers and hydraulic controls have been used extensively as a means to manage groundwater at construction sites. In these applications, the purpose of the installations is to stop the flow of groundwater into the site during the time at which the construction activities are ongoing. The extension of these technologies and their adaptation to the management of NAPLs and contaminated groundwater has occurred over the past several years. In these applications, the purpose is to manage the subsurface flow of these liquids to control their movement both within and from a site.

The critical issues associated with the use of physical barriers are the depths to which they can be installed and their compatibility with the contaminants at the site. In most instances, it is necessary to install the barrier to a depth that will permit its contact with the first confining layer in the subsurface geology that is continuous across the site. This contact ensures that the subsurface liquids will not pass beneath the barrier. As the depth to the confining layer increases, certain barrier types become impossible to use because of their construction and/or installation techniques.

Similarly, a specific barrier may be inappropriate because its materials of construction are not compatible with the contaminants at a site. In these .instances, the contaminants may eventually result in a breach of the barrier and permit the flow of the subsurface liquids beyond the containment area. Compatibility must be assessed in terms of potential geochemical reactions, dissolution in solvents, and other physical/chemical interactions. Usually laboratory treatability tests are required to make such an assessment.

It is important to note that the use of almost all physical barriers will require some form of subsurface water management. This is required since there will be a tendency for infiltrated surface water and groundwater to collect upgradient of the barrier and to develop a hydraulic pressure head that may negatively impact the longterm performance of the barrier and/or the groundwater flow characteristics of the site. If this is the case, the subsurface water must be withdrawn to maintain the hydrogeologic conditions at the site. The techniques for treating or otherwise managing the subsurface water that is removed are discussed in Section 4.0 of this document. Furthermore, methods such as capping or covering the area of concern are also considered as a means to reduce the contribution of surface water infiltration to this subsurface water management problem. In some situations, hydraulic controls can be used in lieu of or in conjunction with physical barriers. The critical design factor for this approach is the placement of the wells and/or trenches to ensure complete capture of the contaminated media. The specific locations of wells and/or trenches are usually selected based upon subsurface fluid flow and contaminant transport models which have been calibrated using available hydrogeologic field data.

Slurry Walls

Slurry walls are the most common subsurface barriers because they are a relatively inexpensive means of reducing groundwater flow in unconsolidated geologic materials. The term, "slurry wall", is applied to a number of barriers that are constructed in a vertical trench that is filled with a slurry at the time of excavation. The construction of the slurry wall requires special equipment to excavate a trench while a slurry, typically a mixture of soil and bentonite, is pumped into it. As the excavation proceeds downward, the slurry establishes the hydrostatic pressure against the walls to prevent their collapse. The slurry mixture also intrudes into the void spaces of the side wall and increases the strength of the adjacent soil. This side wall intrusion also contributes to the overall low permeability of the wall. It is possible to replace the slurry with other mixtures, such as concrete, by pumping the alternate mixture into the bottom of the trench and displacing the original slurry solution.

Slurry walls are differentiated by the materials that are used to backfill the trench. The two primary types of construction are:

(1) **Soil-Bentonite**. These slurry walls are constructed by backfilling the trench with a mixture of soil and bentonite. Of the major types of slurry walls, this construction offers the lowest overall cost, the widest range of chemical compatibilities, and the lowest permeabilities if properly constructed. At the same time, these walls have the least strength (i.e., highest compressibility), require a large work area, and are applicable primarily to sites that can be graded to near level due to the fluid nature of the slurry.

(2) **Cement-Bentonite**. These slurry walls use a mixture of Portland cement, bentonite, and water to backfill the excavated trench rather than simply bentonite and soil. The slurry hardens in the trench to form the completed barrier. This difference in construction materials results in different compatibilities and costs as compared to soil-bentonite slurry walls. For extremely deep installations, a normal soil-bentonite slurry mixture may be used during excavation and then displaced at a later time with the cement-bentonite mixture.

Since there is often a concern with the compatibility of soil- and cement-bentonite slurry walls and organic contaminants, cement- asphalt emulsions have been explored as barrier materials to address the migration of organic contaminants.

Slurry walls can be utilized in many ways including:

- semicircular placement downgradient of the waste material to prevent migration;
- semicircular placement upgradient of the waste material to prevent groundwater contact with contaminated media and the leaching of contaminants from these media; and
- circumferential placement surrounding the waste to ensure complete isolation (e.g. at a permitted landfill).

Slurry walls are generally used in combination with a cap and various liquid extraction and treatment technologies to mitigate off-site groundwater migration. The performance of slurry walls may be impacted most by improper quality control during construction, chemical attack (e.g. desiccation) by contaminants and subsequent loss of integrity, and intrusion by man.

Slurry walls have been used at MGP sites for the containment of both source materials as well as groundwater. However, the long-term performance of these installations has not yet been established.

Sheet Piles

Sheet pile walls are also commonly used to provide a barrier to control the lateral migration of contaminated subsurface liquids. The cross sectional shape and size of the individual piling sheets are largely determined by the depth requirements of the containment barrier or cell. The individual piling sheets can be made of wood, pre-cast concrete, or steel with the latter representing the most common material of construction.

Construction of a barrier of sheet piles is initiated by interlocking the individual sheets prior to driving them into the ground. The piles are then driven in sections to the desired depth. Drop or vibratory hammers are used to drive the piles into place. Heavy equipment is preferred since lightweight equipment requires more time and can distort the top of the piling. A cap block or driving head is usually placed on top of the piling while being driven to prevent damage from the hammer. Once installed, soil fines are washed into the interlocks between the sheet piles by groundwater flow and form a low permeability barrier. In almost all cases, the seals between the individual sheets are sufficiently tight to retard water infiltration but not to prevent it. If water infiltration is unacceptable, the seams can be grouted; however, this is a costly procedure.

The performance life of sheet piles range between 7 and 40 years, depending on the soil in which they are installed. Sheet piles have been successfully utilized in soils ranging from well-drained sands to impervious clays with pH ranging from 2 to 9. Additional protection of sheet piles from corrosion can be obtained by using hot-dip galvanizing, polymer-coating, or cathodic protection.

Sheet piles have been used at MGP sites, especially during soil and/or sediment excavations. This barrier system has been very effective in these applications as measured by the development of water tight seals. These seals have permitted excavations below groundwater and have prevented the migration of silts into surface water ways during sediment excavations.

Grout Barriers/Curtains

Grouting is a process in which a suitable fluid (grout) is injected into a rock or soil mass to increase its strength or reduce its permeability. Various types of grouts are available for use including cement, clay, bentonite clay, alkali silicates, organic polymers, urea-formaldehyde, epoxy, and polyester. Following injection, the grout hardens in place. Grout barriers/curtains are generally incapable of attaining truly low permeabilities in unconsolidated geologic materials (e.g., sands, silts, or clays) (Spooner, 1983). They are best suited for sealing fractures in bedrock. Even in cases where rock fractures are transmitting large volumes of water, a grout can be injected and harden before it is washed from the formation.

Grout barriers have also been considered as a means to seal the bottoms of gas holders which are suspected of leaking. In some instances, it is desired to isolate these subgrade gas holders rather than to attempt to excavate and remove the structures and contents. In these instances, a grout barrier may be the only means by which a bottom seal can be installed.

Soil Freeze Walls

Soil freeze wails can be used in any type of soil that is at or near saturation with water. The freezing process requires the installation of pipes in the ground through which a freezing brine solution is pumped. Once the ground is frozen, the system must be maintained until the excavation or backfill is completed. Typically, two freezing plants are operated and a third is maintained as a spare.

The specialized nature of this application and the required maintenance make its cost relatively high compared to other techniques. The major factors that influence the cost include the soil properties, the depth of freezing that is required, the thickness of the freeze wall, and the groundwater saturation and movement. In addition to cost considerations, it is also true that few contractors can perform this type of work because of the specialized equipment that is required.

A freeze wail is being used at one MGP site in New Jersey as part of an excavation of a subsurface structure. Its selection over sheet plies at this site was due to two site-specific considerations. First, there was a concern about the structural integrity of the structure during the removal of its contents. The freeze walls addressed this concern by providing sufficient structural support to prevent the development of a pressure differential on the gas holder walls during excavation. Second, the groundwater table at the site was extremely high and the ability of sheet pile to adequately prevent groundwater infiltration was questioned. The freeze wall was installed in late 1993.

Synthetic Membranes

Flexible synthetic liners are often used as a vertical barrier for engineered *in situ* containment. Their application is limited to shallow cutoff walls because installation at depth without extensive excavation is difficult. In some cases it may be desirable to combine a flexible synthetic liner with an earthen liner, such as a slurry wall, to afford maximum containment. This is especially true when floating NAPLs that could degrade the earthen liner are present in the containment area. A flexible synthetic liner that is resistant to the NAPL can be placed inside the earthen perimeter to a depth that is sufficient to prevent contact between the earthen liner and the NAPL.

Hydraulic Control

The onsite containment of NAPL and groundwater can be achieved by installing a collection system that intercepts the subsurface flow as it approaches the site perimeter. The collection and removal methods represent conventional technology that have been applied at many sites. The selection of a specific method for a site typically depends upon the depth of the NAPL and groundwater that will be removed. For example, at relatively shallow depths, well points and suction wells are used most often. (Suction wells are similar to well points but are usually larger in diameter and are used in fewer numbers). For deeper applications, ejector wells are usually selected. Subsurface drainage systems as well as ditches, trenches, and' channels can also be used to collect NAPL and groundwater and/or to lower water tables. These latter techniques are used for situations in which the water table is very shallow, particularly if a floating NAPL is present.

Since hydraulic control requires the recovery and removal of the groundwater from the subsurface zone, the water must be managed after it is brought to the surface. Typically, the volumes of water that are required for treatment are greater than the volumes of water that are generated when physical barriers are used; however, the treatment requirements are not different. Treatment of this water can be accomplished using the technologies that were described in Section 4.0 of this report.

6.1.2 TREATMENT

In situ treatment options, as previously noted, are not generally media-specific since the groundwater, gases, and soil co-exist in the subsurface and contaminants are freely exchanged between these media. Nevertheless, there are some treatment options which are directed primarily towards the unsaturated, or vadose zone. These technologies emphasize the treatment of the contaminated soils. On the other hand, treatment options directed towards the saturated zone focus on the treatment of contaminated groundwater and soil.

Stabilization

Stabilization, as previously discussed, is the process by which contaminant mobility in a solid matrix is decreased through physical and/or chemical means. *In situ* stabilization involves the application of the reactants directly to the soil surface or by injecting them into the contaminated subsurface soils. *In situ* stabilization requires the use of specialized injectors and augers that simultaneously inject the stabilizing agent and mix it with the contaminated matrix. This approach to *in situ* treatment can be conducted in both the saturated and unsaturated zones of the subsurface.

A full-scale application of the *in situ* stabilization of contaminated soil has occurred at an MGP site in Columbus, Georgia. The contaminated soil was located primarily in a 15-foot thick zone below the water table and underlying 10 to 20 feet of miscellaneous fill. The maximum contaminants that were present in the soils were 260 mg/Kg of VOCs, 2400 mg/Kg of PAHs, and 5500 mg/Kg of oil and grease. The stabilization equipment included an eight-foot diameter auger that was advanced using a 100 ton rig capable of developing a torque of 200,000 foot-pounds. Cement additive was introduced as a slurry through the hollow stem auger shaft at controlled rates. The slurry was pumped through exit ports located at the bottom of the auger flights and thoroughly blended with the contaminated soil. A total of 1823 overlapping auger holes were drilled and stabilized, representing a total stabilized volume in excess of 82,000 cubic yards. The duration of the remediation project was twenty weeks. The project was completed in the spring of 1992 and a post-remediation monitoring plan was implemented which included a system of monitoring wells that were installed around the site perimeter. Groundwater samples are collected quarterly and analyzed for VOCs, PAHs, and total cyanide. If no statistically significant concentrations of contaminants are recorded during the initial five years, monitoring will be discontinued. To date, the first two sampling events have yielded no detectable concentrations of VOCs and PAHs; no data was reported for cyanide concentrations.

As applied to contaminants in groundwater, stabilization involves the processes of adsorption, ion exchange, and precipitation. Adsorption is applicable to both organic compounds and metals and is achieved by injecting absorbants or complexing agents that bind the contaminant into a complex that strongly adsorbs to soil. Ion exchange applies to metals and requires the alteration of the cation exchange capacity of the soil to immobilize cationic metals. Precipitation involves the complexing of metals with chemical reactants that precipitate soluble metals and render them immobile. However, in all of these cases, there is a general concern that the aquifer will become clogged by the products of the physical or chemical reactions that occur in the subsurface. As such, this approach has not been frequently used; rather, the groundwater is usually extracted before it is subjected to this type of treatment.

Extraction and Flushing

The *in situ* treatment of contaminated soils in the vadose zone emphasize the removal of contaminants from the soil through the extraction of subsurface gases. This extraction can be enhanced by applying a vacuum or heat to the subsurface or injecting the subsurface with air. Similarly, soil remediation in the saturated zone is achieved by taking advantage of the partitioning of the contaminants into a different media, in this case, groundwater. As such, removal of the groundwater and/or *in situ* treatment of the contaminants in the groundwater result in the treatment. of .the contaminated soil.

Vapor Extraction

In the unsaturated zone, it is possible to extract the subsurface vapor using a vapor extraction system. The subsurface vapor will contain a number of contaminants, the concentrations of which will be dictated by a number of factors including their concentration in the soil and their respective volatility. By withdrawing the vapor, these contaminants are removed from the subsurface. As the vapor containing the contaminants is displaced, a new equilibrium is established between the replacement vapor and the contaminated soil. Thus, the subsurface vapor is continuously removing contaminants from the contaminated subsurface soil. As vapor extraction proceeds, the concentration of the contaminants in the extracted vapor decreases logarithmically until a residual contaminant concentration is achieved in the vapor phase. This residual concentration represents a non equilibrium condition that is typically dictated by the rate of mass transfer of the contaminants from the soil to the vapor phase. At this point, the extraction of the vapor can be discontinued to reestablish an equilibrium concentration. As such, when vapor extraction continues, the contaminant concentration in the vapor will once again be elevated and eventually decrease to a residual level, perhaps lower than the Original residual concentration, over time. This cycling process is often used to enhance the removal of contaminants.

The partitioning of the contaminants from the soil to the vapor phase can be enhanced using a number of techniques. For example, a partial vacuum can be applied to the subsurface to increase the equilibrium concentration of the contaminant that can be achieved in the vapor phase. Similarly, the equilibrium concentration of the contaminants can be increased by heating the subsurface soil. This heating is achieved by injecting steam or hot gas into the subsurface or inserting electrodes into the soil to transfer electromagnetic energy (radio frequency heating) or high potential electrical discharges (electric heating). The increase in the equilibrium concentration results in the removal of a greater mass of contaminants from the subsurface for a given volume of extracted vapor. Alternatively, air can be injected into the subsurface to increase the volume throughput of vapor for the subsurface. The greater volume of vapor will increase the quantity of contaminant that is removed for a given residual concentration of contaminant in the vapor phase. If the air is injected into the saturated zone, a process known as air sparging, it strips VOCs from the groundwater and into the vadose zone. At this point, the vapor phase contaminants either absorb onto the soil in the vadose zone or travel with the vapor to the ground surface.

In all cases, the contaminated vapor that is extracted from the subsurface must be treated prior to discharge into the atmosphere or injection into the subsurface. One treatment option that is used in Europe, and less frequently in the United States, is soil biofilters. In these systems, the extracted vapor is passed through a soil column which adsorbs the contaminants. The adsorbed contaminants are then continuously biologically degraded by the microorganisms that are present in the soil. The more common vapor phase treatments that are used in the United States are activated carbon or catalytic oxidation.

This technology application works best for the treatment of unsaturated soils that are contaminated with volatile organic contaminants such as benzene, toluene, or xylenes. Its effectiveness is governed by the subsurface site conditions (e.g., soil type, porosity, permeability, percent moisture) and the nature of the soil-contaminant matrix. In general, it may require a substantial amount of time to achieve the desired treatment goals due to the limitations that are imposed by equilibrium and mass transfer considerations.

Aqueous and NAPL Extraction/Flushing

Soft contaminants can also be removed *in situ* by continuously passing an aqueous solution through the contaminated soft. During this process, the contaminants in the soil partition into the aqueous phase and are removed as the aqueous solution is withdrawn from the subsurface. The aqueous solution is then subjected to treatment to reduce the concentrations of the extracted contaminants after which it is usually recycled into the subsurface to minimize the overall water requirements of the system. However, a portion of the treated water may have to be discharged to prevent the build-up of hydraulic pressure as well as inorganic or organic constituents which can contribute to the formation of scale in the recirculation loop.

In situ extraction attempts to remove contaminants which are held in the interstices of the soil particles as well as those which are adsorbed to the soil particles. To aid this process, it is often necessary to enhance the solubilization and/or desorption of the contaminants by placing additives into the aqueous solution. Typical additives include surfactants, chelating agents, acids or bases, or organic solvents. The choice of the additive or additives for a particular application is dictated by the type of contaminants, the soil characteristics, the compatibility of the additive(s) with the subsurface environment and the treatment system that is selected for the recirculated groundwater. For the most part, it is desirable to add only traces of the additives since they may complicate the development of an acceptable water management scheme.

In situ flushing is similar to *in situ* extraction with the exception that it is usually targeted for the removal of free-phase hydrocarbons or NAPLs. Steam flushing is one technique that can be used for secondary oil recovery and for primary production of heavy oil and tar sands bitumen. The steam is used to heat the NAPL deposit, which decreases the density and viscosity of the NAPL to near that of water. With a density and viscosity similar to that of water, the hot steam condensate can dislodge the NAPL and provide a motive force for its displacement from the subsurface. Typically, the NAPL and hot condensate are removed from the subsurface via extraction wells.

Aboveground, the NAPL and water are separated. VOCs are then removed from the water prior to injection into the subsurface. The quantity of water that requires treatment is a function of the amount of steam that is injected into the subsurface and the amount of groundwater that is removed with the NAPLs. An alternative to steam injection is the injection of a water soluble polymer. The purpose of the polymer is to increase the density and viscosity of the groundwater to that of the NAPL. Once again, with a similar density and viscosity, the NAPL and water can be removed from the subsurface using conventional recovery wells.

In situ flushing is often used prior to the application of *in situ* extraction or other *in situ* treatment techniques. The flushing is capable of removing the gross contamination that is represented by the free-phase hydrocarbons and permits a more effective use of extraction and/or chemical treatment and biological oxidation for the treatment of the residual concentrations of contaminants that remain in the soil and groundwater system. However it should be understood that *in situ* flushing is incapable of removing more than 70% of any free-phase hydrocarbons from the subsurface. The remaining 30% of the hydrocarbon is trapped within the interstices of the soil and is known as the residual saturation. While 70% removal is substantial, the remaining hydrocarbon may still be problematic from an environmental perspective and may be difficult to treat with conventional *in situ* treatment technologies.

Biological Treatment

Most soils in the subsurface contain a consortia of bacteria which collectively have the ability to degrade a broad range of organic compounds. The bacteria which are typically most useful for environmental remediation are aerobic bacteria since they are usually already present in the soil, especially near the ground surface and in the vadose zone. In the saturated zone, it is likely that there are fewer numbers of aerobic bacteria and more anaerobic bacteria. This is true simply because the solubility of oxygen in the groundwater is less than the oxygen concentration in air. Providing that the environmental conditions are adequate, these naturally-occurring bacteria are capable of biologically degrading the contaminants without human intervention, a process called "intrinsic" bioremediation. However, when large quantities of organic chemicals are present in the subsurface, this natural biodegradation process is often limited by the availability of dissolved oxygen or other electron acceptors, and at times, by the availability of other nutrients. In these cases, bioremediation requires the addition of microbe-stimulating materials, a process called "engineered" bioremediation. This process relies on the acceleration of the desired biodegradation reactions by encouraging the growth of more organisms as well as by optimizing the environment in which the organisms must perform the detoxification reactions.

The suitability of a site for bioremediation depends upon the biodegradability of the contaminant as well as the geological and chemical characteristics of the site. For the most part, indigenous microorganisms can detoxify an array of contaminants; however, some compounds are more easily degraded than others. For example, most of the current applications of *in situ* bioremediation have focused on petroleum hydrocarbons or their derivatives, i.e., gasoline, fuel oil, diesel oil, and kerosene. The important site considerations are different for intrinsic and engineered bioremediation. For intrinsic bioremediation, the critical site characteristics are consistent groundwater flow throughout the year, the presence of minerals that can prevent changes in pH, and elevated concentrations of oxygen, nitrate, sulfate, or ferric iron. For engineered bioremediation, the key site characteristics are permeability of the subsurface to fluids, uniformity of the subsurface geology, and relatively low concentrations of residual concentrations of NAPLs (less than 10,000 mg/Kg).

Intrinsic Bioremediation

This approach to bioremediation is an option when the naturally occurring rate of contaminant biodegradation is faster that the rate of contaminant migration. These relative rates depend upon the type and concentration of the contaminant, the microbial community, and the subsurface hydrochemical conditions. The rate controlling step is frequently the influx of oxygen. When natural oxygen supplies become depleted, the microbes may not be able to act quickly enough to contain the contamination. The lack of a sufficiently large microbial population can also limit the rate of contaminant removal. The microbial population may be small because of a lack of nutrients, limited availability of contaminants resulting from sorption to solid materials or other physical phenomenon, or an inhibitory condition such as low pH or the presence of a toxic material. The rate at which the native microbes act on a contaminant must be examined in field tests or laboratory tests that are conducted on site-specific samples. At the same time, any physical or chemical conditions that may inhibit that rate should also be identified. Lastly, the effectiveness of intrinsic bioremediation must be continually monitored by analyzing the fate of the contaminants and other reactants and products indicative of biodegradation.

The feasibility of intrinsic bioremediation in the saturated zone has been demonstrated at an MGP site in upstate New York. This site was a "dump" site for coal tars from a neighboring manufactured gas plant. The tar was placed in a large trench at the side of a country road and covered with sand. The amount of tar that was deposited in the trench was estimated to be anywhere from 4000 to 16000 gallons. In the early 1980s, a utility worker detected coal-tar derived organic contaminants several hundred meters downgradient from the tar deposit and an investigation of the site was initiated. The site was extensively characterized to delineate the nature and extent of the tar deposit as well as the contaminant plume location and definition. With this information in hand, the tar deposit was removed in the summer and fall of 1991 and an intensive groundwater monitoring program was initiated with the intention of documenting contaminant migration in the groundwater over a ten year period. Two rounds of groundwater monitoring were completed prior to the removal of the tar deposit (1989 and 1990) and four rounds of monitoring have been completed since its removal. A comparison of these results have indicated that natural processes are influencing the migration of the contaminants. Based on these comparisons, it appears as if the concentrations of the contaminants in the groundwater are actually decreasing with time since the removal of the tar deposit took place. However, the extent that intrinsic biological processes are contributing to this observation has not yet been quantified. Additional studies in the laboratory and in the field are planned to assist in the quantification of the role of intrinsic bioremediation in the subsurface zone of this site.

Engineered Bioremediation

This approach to *in situ* bioremediation may be chosen over intrinsic bioremediation because of time and liability. Typically, engineered bioremediation accelerates the biodegradation reaction rates which minimizes the time for site remediation. The shorter time requirements reduce the liability for the costs required to maintain and monitor the site.

Saturated Zone. Engineered bioremediation in the saturated zone usually consists of either a set of injection and recovery wells to circulate oxygen and nutrients dissolved in water or a set of compressors for the injection of air. The recirculation of the enriched water through the contaminated subsurface soil promotes the growth of indigenous microorganisms for the subsequent biodegradation of contaminants. The naturally occurring bacteria utilize the organic contaminants both as an energy source and a food source. Oxygen is usually added as hydrogen peroxide (H_2O_2); however, in some instances, an alternative electron acceptor is required for biological treatment to occur. Nitrate, in the form of sodium nitrate ($NaNO_3$), is often used as an alternative to oxygen when anaerobic conditions are preferred over aerobic conditions. Surfactants can be added to aid in the desorption of chemical contaminants from soil particles into the water phase. The desorption of the contaminants from the soil is considered important since it is believed that the contaminants must be in the aqueous phase for biodegradation to occur. However, there are no field studies to date which have demonstrated the benefits to bioremediation that have resulted from adding surfactants to the subsurface environment.

The recirculated groundwater is usually introduced into the subsurface using injection wells or a french drain system. Extraction wells or trenches recover the groundwater downgradient from the point of injection. The extracted groundwater may require additional treatment aboveground prior to its discharge or injection into the subsurface. Typical aboveground treatment of the groundwater may only involve NAPL/water separation or it may also include air stripping, carbon adsorption, or biological treatment for the reduction of soluble contaminants. Biological treatment of the groundwater is often considered if there is a need to inject additional microorganisms into the subsurface zone. These microorganisms will be present in the effluent from most biological treatment systems that are used to treat the groundwater. However, the addition of microorganisms into the subsurface has not enhanced. the results of *in situ* bioremediation based upon the available data in the literature. This lack of impact is believed to be the result of the inability to properly transport and distribute the microorganisms into the subsurface zone of contamination.

Although microorganisms in the laboratory can destroy most organic contaminants, the physical realities of the subsurface such as low fluid rates, physical heterogeneities, unknown amounts and location of contaminants, and the unavailability of contaminants to the microorganisms, make its implementation a technological challenge. Four strategies can help minimize the uncertainties that are introduced by these factors: (1) increasing the site characterization efforts to better document the presence of contamination, (2) using models to guide the design and evaluation of the system performance, (3) increasing the number of samples used to characterize the system performance, and (4) compensating for uncertainties by building safety factors into the design of the engineered systems. These strategies should play an important role in the successful implementation of *in situ* bioremediation at MGP sites.

Vadose Zone. Biological oxidation of the contaminants in the unsaturated zone, sometimes referred to as bioventing, is possible but generally not without some form of stimulation. The most common form of stimulation is the addition of amendments such as moisture, nutrients, and electron acceptors (i.e., oxygen) into the subsurface environment. These amendments 'are meant to provide an environment that is conducive to the growth of the indigenous microorganisms which are assumed to have the ability to biodegrade the contaminants in the soil matrix.

The systems which are used to deliver the amendments to the subsurface can be divided into two categories: (1) gravity/forced hydraulic delivery and (2) extraction/injection air delivery methods. Gravity delivery methods include flooding, ponding, ditches, and sprinkler systems which deliver water that contains nutrients and dissolved oxygen to the contaminated area by applying it to the soil directly over the contaminated area. Forced hydraulic delivery systems are used to deliver the water under pressure into a contaminated area through well points (i.e., groundwater wells). Air delivery systems, if required in addition to the water delivery systems, include both extraction or injection methods that are similar to those used for vapor extraction. Extraction systems incorporate vacuum extraction techniques where a low flow of fresh air is continually pulled through the contaminated zone. Injection systems deliver fresh air to the contaminated zone under pressure through well points and the air is allowed to permeate through the contaminated zone back to the surface. An injection system can be installed with one or more companion extraction wells to achieve a more extended horizontal flow of the air.

This approach to treatment of contamination in the unsaturated zone is applicable to contaminated media such as the vapor phase and soil. It is not particularly applicable if NAPLs (i.e., DNAPLs and LNAPLs) are present. However, it can be used in combination with technologies that are designed to remove these NAPLs prior to its application.

Chemical Oxidation

In situ chemical oxidation is a potentially viable approach to remediate soil and groundwater. A groundwater injection and recovery system is required to provide for the efficient transport of the chemical oxidant through the contaminated zones without either plugging the aquifer or spreading the contamination. Injection wells or french drains can be used to introduce recirculated water that has been dosed with a chemical oxidant into the contaminated zone. Extraction wells or trenches can be used to recover the treated groundwater downgradient from the point of injection. Often, recovered groundwater passes through an aboveground treatment system prior to injection into the subsurface. Furthermore, containment barriers may be necessary to provide adequate control of the subsurface migration of the site contaminants.

Potential chemical oxidants include potassium permanganate, hydrogen peroxide, ozone, chlorine and chlorine dioxide. Solutions of these oxidants have viscosities and densities that are similar to water and they are not highly reactive. The treatment effectiveness can be greatly .hampered by the natural soil organic materials or other oxidizable soil constituents such as reduced iron or manganese. On the other hand, metals that are typically found in soil may enhance the oxidation by serving as catalysts for the oxidation reactions. Lastly, the combination of reduced iron and hydrogen peroxide, otherwise known as Fenton's Reagent, has also been documented as a potential oxidant which can partially oxidize organic contaminants and improve their susceptibility to biodegradation.

7

CONCLUDING OBSERVATIONS AND REMARKS

The challenges that are posed during the remediation of MGP sites, while unique in some aspects, are not unlike those associated with other sites upon which petroleum- or coal-derived hydrocarbons have been managed. All of these sites often have contaminated soil, sediment, and groundwater which are contaminated with VOCs, PAHs, inorganic sulfur and nitrogen, and selected heavy metals. In addition, it is not unusual to find free-phase hydrocarbons in tanks or vessels as well as in the subsurface where they lie on the groundwater (Lighter-than water Non-Aqueous Phase Liquids or LNAPLs) or at the bottom of the aquifer (Denser-than-water Non-Aqueous Phase Liquids or DNAPLs). The uniqueness of MGP sites is associated with the process structures of the industry such as subgrade gas holders, tar separators, and tar wells; the characteristics of the process residuals such as carbonated water gas tar and spent purifier box materials; and the evolution, growth, and decline of the industry which led to specific patterns of operation, demolition, and site use. This combination of factors means that the utility industry can look to other industries such as petroleum refining, wood treating, and iron and steel manufacturing to identify viable remediation strategies for their MGP sites but that they will also have to generate an industry- and site-specific data base for each technology to complete a proper evaluation of its performance capabilities, economics, and reliability.

The utility industry has begun to generate an MGP site remediation data base through the actions of both its trade associations and individual utilities. This data base is being generated at a variety of scales, from laboratory and pilot tests .to field demonstration tests and full-scale site remediations, using a variety of site residuals including free-phase hydrocarbons, purifier box wastes, contaminated soil and sediment, and contaminated groundwater from every type of MGP process (i.e., coal gas, carbonated water gas, and oil gas). The strength of this data base is in the integration and cross correlation of the results for the identification of successful and unsuccessful treatment strategies as well as unique responses to treatment that are indicative of industry-specific waste characteristics. Efforts such as the preparation of this report and others that have been produced by EPRI, GRI, and selected utilities over the past one or two years represent the first attempts to draw upon this base of experience to distill the problem of MGP site remediation into a more manageable one. This report does not provide the final answer for any given site but it does focus the review to a subset of remediation technologies that should be capable of achieving most site-specific remediation goals. In effect, the information provided in this report can serve as the framework for the development of presumptive remedies for MGP sites.

Brief summary comments for each of the areas of remediation that were presented in this report are provided in the remainder of this section. These comments are provided in the context of the overall site management options which include both *ex situ* and *in situ* management techniques.

7.1 *EX SITU* TREATMENT OF CONTAMINATED WATER

The treatment of contaminated groundwater is reasonably well understood. There exist conventional unit operations which are more than capable of removing the critical contaminants that are present in the contaminated water at MGP sites and their use at any given site, alone or in combination with other treatment technologies, will be dictated by the discharge requirements that have been specified. It is believed that discharge requirements can be met for the primary disposal options which include discharge to a POTW, a surface water body, or the subsurface. The primary variable is cost since more restrictive discharge requirements may require longer reactor residence times (and hence, larger reactors for a given water flow rate), the use of more chemical reactants, or the use of additional treatment technologies. For this reason, there may be a need to optimize the remediation strategy at any given site to minimize the overall cost. This can be done using conventional laboratory treatability studies. Additional research in contaminated water remediation, if any, should emphasize the reduction in the cost of treatment through the application of innovative approaches to treatment.

The most uncertain aspect of contaminated water remediation is the ability to predict the quality and flow rate of the groundwater that will be generated during a site remediation. The heterogeneity of the subsurface of most MGP sites makes it very difficult to predict these parameters. For example, it is not uncommon for groundwater flow models and pump tests to over predict or under predict recovery by a factor of two to ten which then reeks havoc on the water treatment system which was designed for a much narrower range of groundwater flow rates. Clearly, more research is required to develop better techniques to design this aspect of groundwater remediation and caution is advised when using current techniques to do so.

7.2 *EX SITU* TREATMENT OF SOURCE MATERIAL AND CONTAMINATED SOLID

The treatment of source material and contaminated solids is not as well developed as that for groundwater. This is simply a direct result of the fact that water treatment has been practiced for nearly 25 years whereas solids management, beyond landfills, has only been practiced for, at most, half as long.

7.2.1 THERMAL TREATMENT AND LANDFILL DISPOSAL

The proven treatment options for these MGP site residuals are still thermal treatment and landfill disposal. Thermal treatment will always be considered for use because of its ability to effectively treat all of the organic contaminants and forms of residuals that have been found at MGP sites. This treatment may require the preprocessing of the residuals such as materials blending for high-BTU hydrocarbons or high-sulfur purifier box wastes; nevertheless, it is likely that all of the residuals can be handled in some manner. The thermal treatment will most likely have to occur offsite since the use of an onsite unit can rarely be justified due to the low volumes of these residuals that are typically generated at any one MGP site. Both incineration and thermal desorption units have been demonstrated as effective on the contaminated solids although the latter may not be capable of processing the pure source materials.

Landfill disposal has remained viable simply because the land disposal restrictions have not been applied to MGP site residuals and the cost has remained low. This may change in the not so distant future since the U.S. EPA has. recently proposed universal treatment standards for contamination soils that fail the organic toxicity characteristic (TC) test, some of which have been found at MGP sites. For those soils, a specific contaminant concentration or percentage reduction of the contaminant concentration will be required prior to its final disposal. Treatment requirements have been established for 200 contaminants which include several PAHs, VOCs, and metals. The regulations that will determine the applicability of these requirements to MGP site residuals will be finalized in July, 1996. These regulations will designate which of the former Bevill Mineral Processing wastes, of which hydrocarbons from MGP sites is one, will be subject to the land-ban restrictions. These regulatory developments, combined with the long-term liability associated with any land disposal option, may eventually make the landfill disposal of MGP site residuals an unattractive option.

7.2.2 UTILITY BOILERS, STABILIZATION, AND RECYCLE ALTERNATIVES

Treatment options which are rapidly escalating in importance and interest are co-burning in a utility boiler, stabilization, and recycle alternatives.

Co-burning in a utility boiler is an extension of thermal treatment although it is done entirely under the control of the utility. This treatment option represents a practical use of utility boilers although there are concerns about impacts on the facility operation as well as the status of its environmental permits. However, to date, there have been feasibility studies and test burns completed which indicate that the management of contaminated solids in these units can be done in an environmentally acceptable manner.

Stabilization, alone or in combination with landfill disposal, has also recently gained momentum as a remediation option for contaminated solids. Vendors continue to introduce new stabilization mixes which they claim are capable of treating both organic and inorganic contaminants; however, there are still no monitoring data available from a stabilized monolith to document its long-term stability in the environment.

Furthermore, it is not clear how stabilization will be evaluated as part of the newly proposed universal treatment standards.

The recycle of the contaminated solids into products such as asphalt, aggregate, brick, or cement has the public and technical appeal that fits well into the overall environmental strategies of gas and electric utilities. Accordingly, the investigation of these options has increased substantially over the last couple of years. Basically, the technical feasibility of all of the options has been demonstrated at least once using MGP site residuals although it is clear that each utility will most likely want to conduct their own demonstration test to convince themselves that their materials are compatible with the selected product and that the selected vendor is indeed qualified to do the job. Furthermore, the economics are very attractive based upon actual bids which were recently received by a northeast utility. The primary outstanding issues of concern are the environmental acceptability of the operations of the recycle vendor, the environmental liability associated with the product, and the availability and capacity of qualified vendors.

7.2.3 PHYSICAL, CHEMICAL, AND BIOLOGICAL TREATMENT

Aeration, biological treatment, aqueous/solvent extraction, and chemical treatment are remediation technologies whose performance is very sensitive to the nature of the soil-contaminant matrix. As a result, their performance is very contaminant specific and can vary substantially from site to site. For example, aeration is only effective for VOCs and biological treatment, aqueous extraction, and most forms of chemical treatment are effective only for contaminants that are soluble in water. For this reason, they have not been used extensively for MGP site remediation. However, it is envisioned that their use will increase as more integrated combinations of technologies are used to fully remediate contaminated sites and as regulators begin to accept risk-based clean-up goals for site remediation. The latter point is extremely important since clean-up goals that are based on the aqueous leachability of the contaminated matrix (i.e., the protection of groundwater) would be achievable by these aqueous-based treatment technologies. In the event that remediation goals for a site are below the treatment capabilities of the aqueous-based treatment systems, more emphasis will be directed towards the use of processes which use hydrocarbon solvents to enhance the degree of treatment that is achievable. These processes tend to be more complex than the aqueous-based treatment processes and tend to introduce additional health and safety considerations associated with the storage and management of the hydrocarbon solvents. Consideration of the hydrocarbon solvent extraction processes would also warrant further consideration of thermal treatment options. In any event, the application of aeration, biological treatment, aqueous/solvent extraction, and chemical treatment technologies to a site will require site-specific treatability studies and/or onsite field demonstration tests.

7.3 *IN SITU* MANAGEMENT

In situ containment techniques are available from the general construction industry although their performance for environmental applications has not been thoroughly examined. On the other hand, *in situ* treatment techniques have not been applied extensively under any conditions and represent developing and/or evolving approaches to site remediation. The fact is that most of these techniques can be installed and operated at a site; however, the efficiency of their application is not well understood since the ability to document the treatment efficiency is difficult, at best. For this reason, it is imperative that the site remediation goals be carefully negotiated when an *in situ* approach to treatment is proposed and that the specifications for the measurement of success be explicitly defined prior to the initiation of the remediation. It should be noted that these applications, in spite of their drawbacks and uncertainties, can be appropriate for the remediation of properties that will remain in the ownership of the utility and for which no immediate future use has been planned. In these instances, the *in situ* treatment techniques will, at a minimum, prevent offsite migration of the contaminants and, at a maximum, effect onsite treatment such that the treatment can be terminated in the not so distant future.

8

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A

TECHNOLOGY DESCRIPTIONS

EX SITU TREATMENT OF CONTAMINATED WATER

ACTIVATED SLUDGE

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, ammonia, and conventional pollutants such as BOD, COD, TOC, and total suspended solids.

RELEVANT INDUSTRIAL EXPERIENCE:

Wide application to contaminated water from the wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Lab- and pilot-scale studies as well as full-scale demonstration tests have been conducted on contaminated water from MGP sites.

DESCRIPTION:

Activated sludge processes use a biological slurry containing an active mass of bacteria to achieve microbial oxidation and assimilation (treatment) of organic and some inorganic contaminants in contaminated water. A typical process schematic of a conventional activated sludge system is shown in Figure A-1. Initially, it is likely that the influent water will be subjected to pretreatment for the removal of insoluble material such as suspended solids or free phase oil and tars. Following pretreatment, the influent water enters an aeration tank where it comes into contact with a suspension of microorganisms. The contents of the aeration tank are designated as the mixed liquor. Under proper conditions, the microorganisms in the mixed liquor convert the organic contaminants into microbial cells, carbon dioxide, and water.

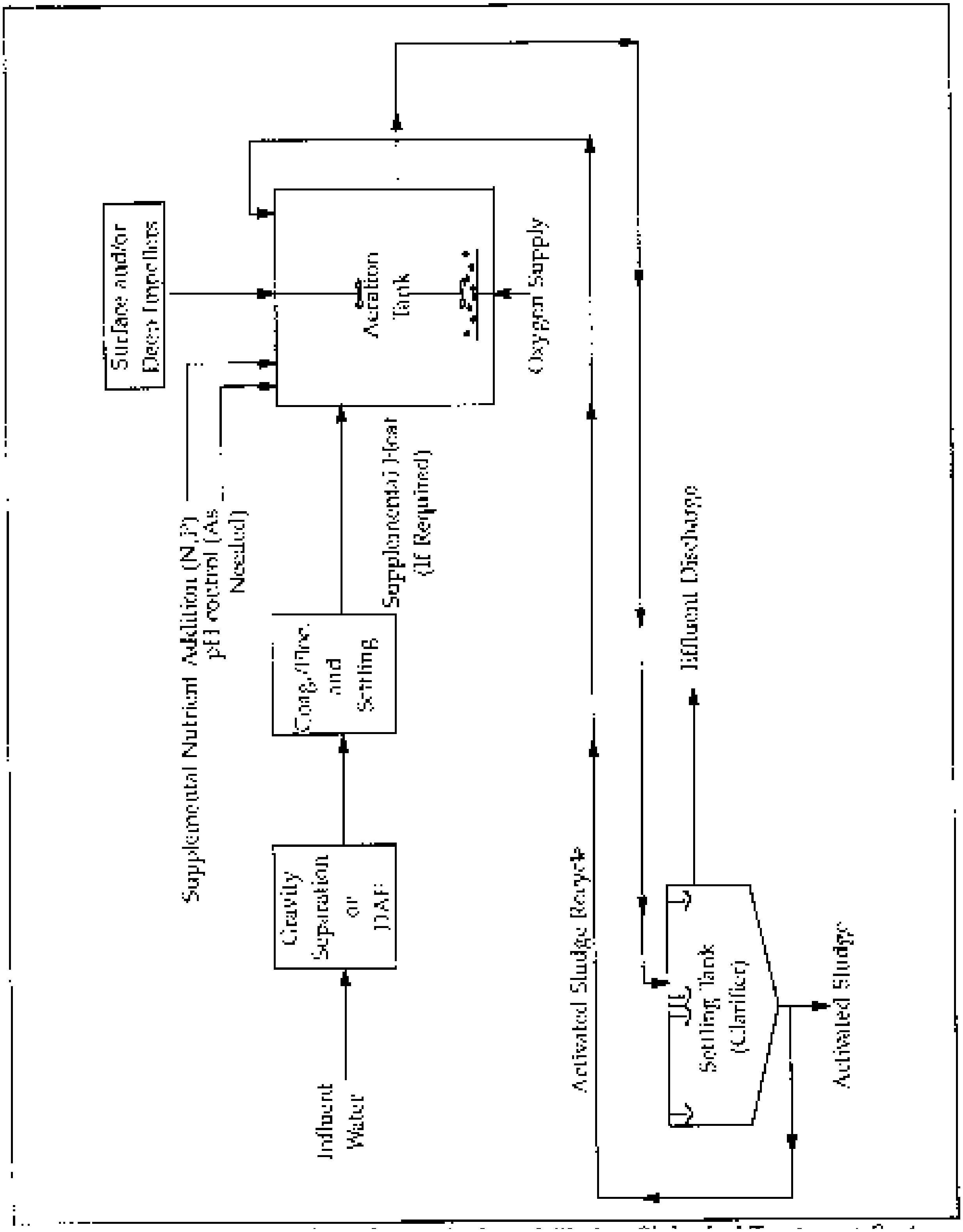

Figure A-1. Process Flowsheet for an Activated Sludge Biological Treatment System.

Industrial aeration tanks often have surface and/or deep impellers to provide complete mixing of the influent water and mixed liquor. Compressed air is injected to add oxygen which ensures the presence of aerobic conditions for the microorganisms. The pH of the influent water and mixed liquor must also be controlled at or about neutral conditions to provide a proper environment for biological action. Supplemental nutrients in the form of nitrogen and/or phosphorus (N,P) are also usually added if the influent water is deficient in these. nutrients. In colder climates, supplemental heat may be required to maintain the reactor temperature between 15°C to 25°C which is optimal for biological activity.

Retention time of the contaminated water in the aeration tank is one of the most important process parameters for biological treatment. This is called the hydraulic retention time (HRT) and is defined as the ratio of the aeration tank volume (v) to the influent water flowrate (Q). Another important process parameter is the solids retention time (SRT) which is the length of time that the biomass (biological solids) remains in the aeration tank-settling tank system. It is also called the mean cell residence time of the microorganisms.

The mixed liquor passes from the aeration tank to a settling tank or clarifier where the microbial solids are separated from the treated effluent. The clarified effluent is then discharged. Discharges from activated sludge systems may go to a publicly owned treatment works (POTW), be routed to surface waters under a National Pollution Discharge Elimination System (NPDES) permit, be reused, or be injected into the subsurface. Prior to any of these discharges, additional treatment such as sand filtration and/or activated carbon may be needed to meet specific discharge requirements for selected contaminants.

The settled sludge from the clarifier is concentrated, via gravity thickening, and most of it is recycled back to the aeration tank. The remaining portion of the sludge is sent to disposal (i.e., "wasted"). The portion of sludge that is returned is referred to as recycle sludge, and is used to maintain the desired concentration of microorganisms in the aeration tank. The ratio of the recycled sludge flowrate to the influent water flowrate is referred to as the recycle ratio (r). The quantity of wasted sludge corresponds to the quantity of new cell' tissue or solids produced from the microorganisms. Wasted sludge usually receives some additional treatment (thickening, dewatering) prior to its ultimate disposal. The degree of wasting ultimately determines the system SRT. For example, at a low wasting rate, the SRT will be relatively high, since solids will remain in the system longer.

One of the main criteria which determines the applicability of activated sludge treatment is the concentration of organic contaminants present in the influent water. Specifically, the influent water must contain a BOD_5 (five-day biochemical oxygen demand) concentration of at least 40 mg/L. This concentration is needed to sustain a viable biological mass in the system. Influent organic concentrations less than 40 mg/L would the require use of an alternative biological treatment process.

PERFORMANCE:

Activated sludge treatment is a proven technology for the removal of biodegradable organic and inorganic contaminants from domestic and industrial process wastewaters and from contaminated water that is generated at inactive, contaminated sites. Most applications on contaminated water from MGP sites have involved the activated sludge treatment plants of a publicly owned treatment works where the water was discharged directly or following limited pretreatment.

It has been demonstrated that a properly designed and operated activated sludge treatment system can achieve the following percent reductions from the aqueous phase:

- more than 99 percent phenols as measured by the standard method, 4-amino antipyrene);
- between 80 and 99+ percent total PAHs;
- greater than 99 percent VOCs;
- greater than 99 percent oil & grease;
- greater than 80 to 99+ percent total organic carbon;
- greater than 90 to 99+ percent ammonia and free/weak-acid dissociable cyanide;
- greater than 99 percent thiocyanate; and
- greater than 99 percent soluble BOD_5.

The most definitive study of activated sludge treatment of contaminated water from MGP sites was a pilot study conducted jointly by GRI and the Niagara Mohawk Power Corporation. The results of this study indicated that contaminant removal is achieved largely by biodegradation although volatilization contributes significantly to the removal of benzene and over half of the 5- and 6-ring PAHs report untreated to either the treated effluent discharge or the "wasted" sludge. At the same time, the activated sludge treatment system operated normally and showed no negative effects of the co-treatment of the MGP site water.

Since the completion of the GRI study, several utilities have discharged contaminated water from MGP sites to POTWs. These discharges have occurred with and without pretreatment. One utility also conducted a field demonstration test to document the fate of the contaminants in the biological treatment system. This information was presented to the city officials to support a discharge permit application.

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ACTIVATED SLUDGE—NO RECYCLE (AERATION TANK)

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, ammonia, and conventional pollutants such as BOD, COD, TOC, and total suspended solids.

RELEVANT INDUSTRIAL EXPERIENCE:

Wide application to contaminated water from the wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Lab- and pilot-scale studies have been conducted on contaminated water from MGP sites and a full-scale demonstration test is planned by the Gas Research Institute in 1994.

DESCRIPTION:

The activated sludge treatment system with no recycle is a biological process which uses microorganisms to aerobically biodegrade aqueous phase contaminants. It differs from a conventional activated sludge system in that there are no provisions for solids settling and recycle. Thus, the length of time that. the contaminated water is in the aeration tank is sufficiently long to allow for growth of the microorganisms; this is generally four to five times longer than a conventional activated sludge system. The process mixes a biological slurry containing an active mass of microorganisms with the contaminated water in an aeration tank where microbial oxidation and treatment of the contaminants occur. Here, the organic contaminants serve as carbon and energy sources for microbial growth, and are converted into microbial cell tissue and oxidized end products (mainly carbon dioxide and water). After a specified time in the tank, the mixture of bacterial solids and treated water, also known as mixed liquor, is discharged. The biological solids generated from the microbial process are carried over with the treated water for subsequent processing and/or for discharge. The concentration of these solids can range between 100 to 1,000 mg/L depending upon the mass of organic contaminants that are treated.

Figure A-2 shows a process flowsheet for a typical activated sludge treatment system with no recycle.

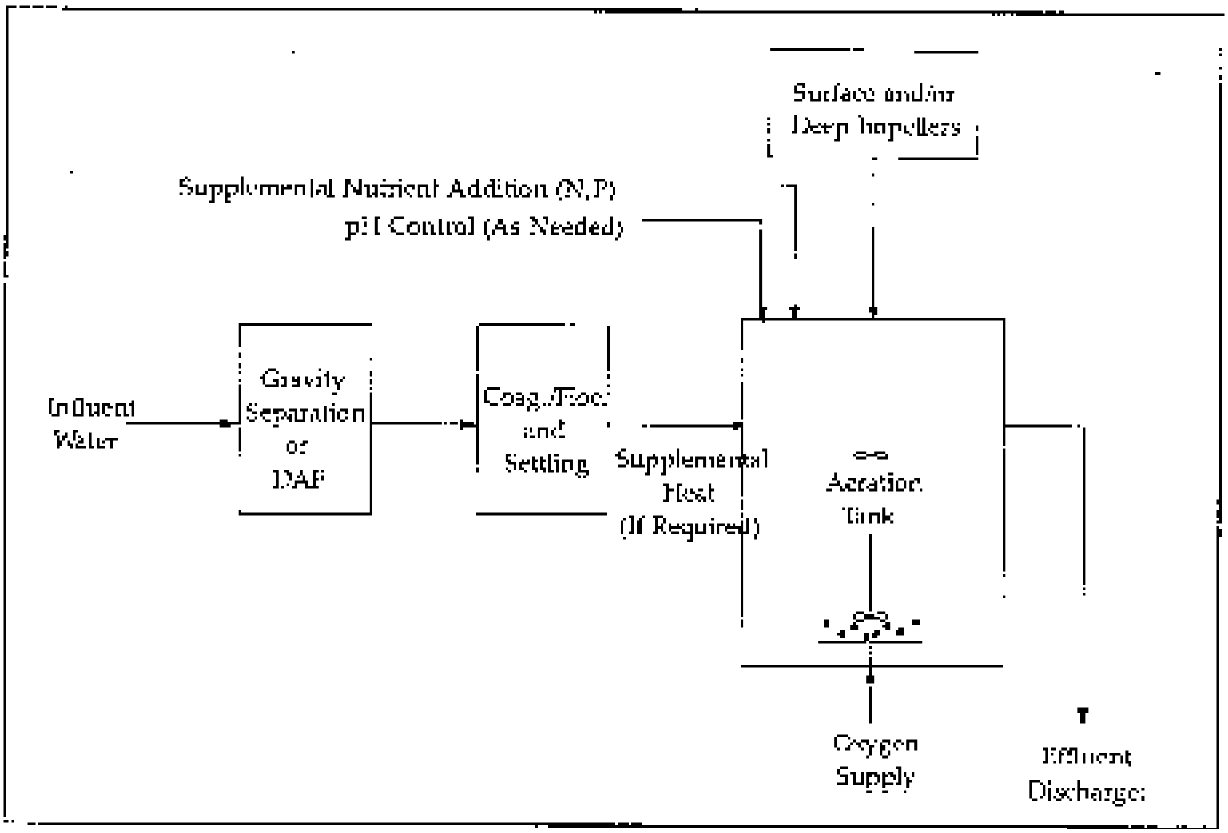

Figure A-2. Process Flowsheet for an Aeration Tank System.

The use of the activated sludge treatment system with .no recycle can be combined with a solids removal step, such as filtration, if the solids cannot be disposed of with the treated effluent. Some of the design equations for a complete mix activated sludge system may be used to design this process. Since there is no sludge recycle in the system, the hydraulic retention time (HRT) equals the solids retention time (SRT). Generally, the SRT and HRT are set between 4 to 10 days, with 5 often being optimal. As with conventional activated sludge systems, laboratory- and pilot-scale treatability studies are useful in obtaining optimal design criteria for these systems.

One advantage of the activated sludge treatment system with no recycle is that the process can handle minor fluctuations in influent water quality. Small changes in the concentrations of organic contaminants usually will not cause a problem; however, if there is a substantial change in the quality of the influent water, an upset condition can occur. These conditions can be avoided through the installation of equalization or storage tanks. Another advantage is that the activated sludge treatment system with no recycle usually has lower operating and maintenance costs associated with it when compared to a conventional activated sludge system, mainly because there is no sludge disposal or handling. However, as previously mentioned, solids removal from the treated effluent may be needed.

PERFORMANCE:

An activated sludge treatment system with no recycle is a proven technology for removal of biodegradable organic contaminants from domestic wastewaters and contaminated waters from inactive industrial sites that contain coal- and oil-derived hydrocarbons. A properly designed and operated process can generally achieve the following percentage reductions of contaminants:

- greater than 99 percent phenolics,
- between 60 and 99 percent oil & grease, and
- between 80 and 98 percent total organic carbon.

Detailed performance data for other contaminants such as PAHs and VOCs are not available in the general literature although it is expected that reductions similar to those in conventional activated sludge treatment systems can be achieved.

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Alessi, C. J., et. al., Design and Operation of the Activated Sludge Process, Water Resources and Environmental Engineering Research Report No. 78-2, Department of Civil Engineering, SUNY at Buffalo, NY, 1978.

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AIR STRIPPING

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

VOCs, selected PAHs (e.g., 2- and 3-ring), ammonia, free/weak-acid dissociable cyanide, and sulfide.

RELEVANT INDUSTRIAL EXPERIENCE:

Wide application to contaminated water from the wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Several lab-scale investigations have been conducted using contaminated water from MGP sites and several full-scale units have been incorporated into site remediation designs.

DESCRIPTION:

Air stripping transfers volatile chemical compounds from the aqueous phase to the gas phase by passing air or an inert gas through the aqueous phase. The efficiency of this separation is based on the mass transfer rates of the compound between the aqueous and gas phases and the ability to achieve equilibrium partitioning between these phases. The equilibrium partitioning that can be achieved is a function of solubility, vapor pressure, and molecular weight of the chemical compound.

A typical process flowsheet for air stripping using a continuous countercurrent packed column is presented in Figure A-3. The influent water to the air stripper should be pretreated for the removal of total suspended solids as well as iron and manganese to prevent the plugging or fouling of the treatment system. The packed column is the most common design that is used for large volumetric flowrates of water, for difficult to separate contaminants, and for the achievement of high treatment efficiencies. The packed column permits the contaminated water to flow uniformly across the surfaces of the packing and provides a high degree of contact between the water and the rising air stream.

As shown in Figure A-3, the contaminated water is usually pumped to a holding tank to equalize its flow and composition prior to treatment. In some instances, pH adjustment may also be required depending upon the chemistry of the contaminants. If heating is necessary to improve the performance of the stripper, the contaminated water is passed through a heat exchanger before entering the packed column. Treated water from the bottom of the column is typically discharged to a treated effluent storage system to allow for monitoring prior to discharge or further treatment.

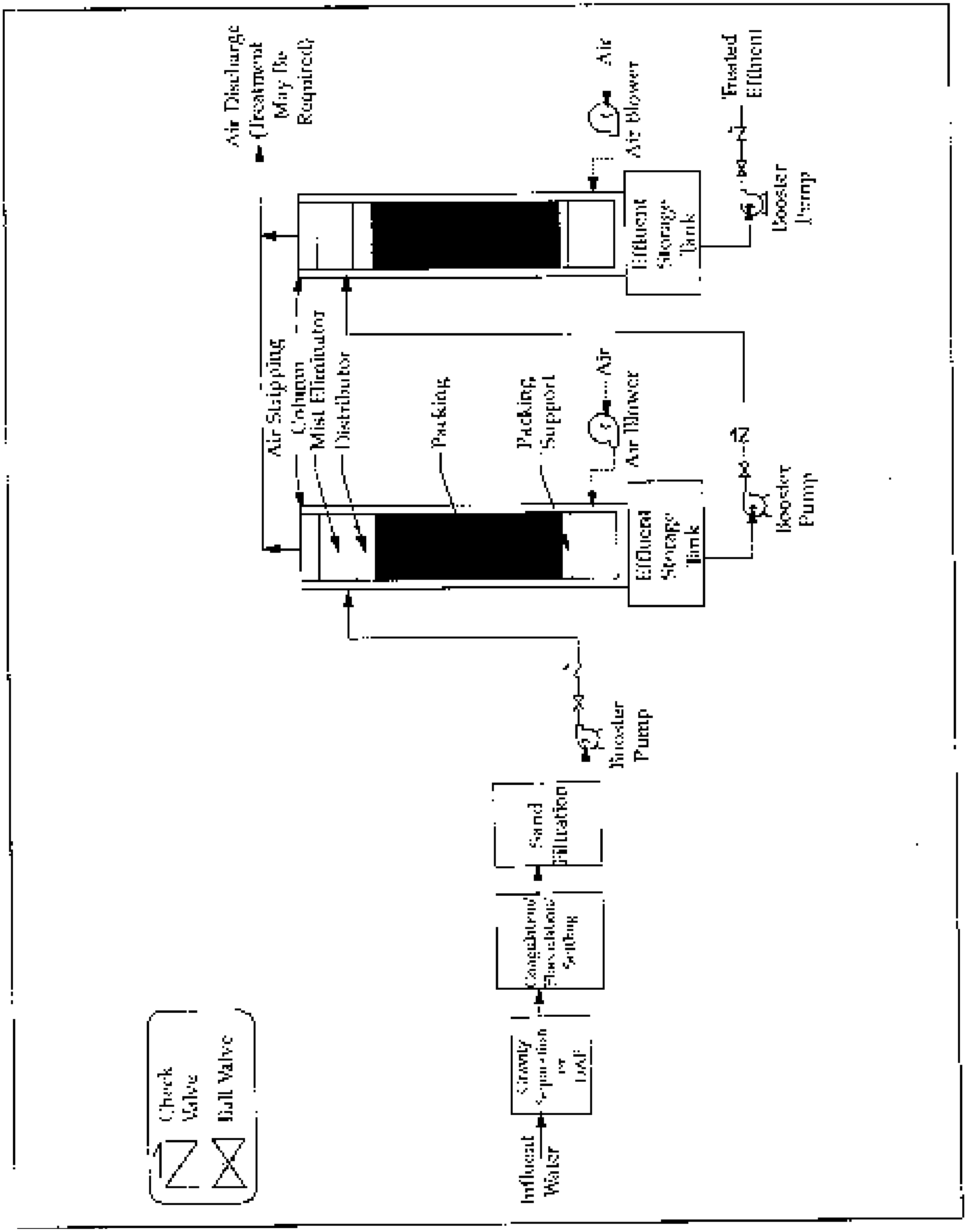


Figure A-3. Process Flowsheet for Air Stripping.

The offgas from the column, which contains contaminants that have been transferred from the aqueous phase, passes through a de-mister and typically requires subsequent treatment in a catalytic oxidizer, a fume incinerator, or an activated carbon absorber before it is discharged to the atmosphere. This offgas can also be sent to an existing flare or fume incinerator if such a unit already exists on site. The selection of the most appropriate offgas treatment process is dependent upon the specific contaminants that require treatment and the emission discharge requirements. Should the contaminant concentrations in the offgas be below the emissions limits prior to treatment, it can be released directly to the atmosphere.

Other modes of air stripper operation include co-current bubble columns and countercurrent spray columns. These alternative designs may be appropriate depending upon the volumetric flow rate and characteristics of the contaminated water. In a co-current bubble column, air is dispersed into the contaminated water through a diffuser which is located at the bottom of the Column. The water also enters at the base of the column and exits the column by means of an overflow weir. This type of stripping unit is particularly applicable to contaminated water with concentrations of total suspended solids that are sufficiently high to cause fouling.

In a countercurrent spray column, water is sprayed into the air through nozzles at the top of the column and is collected in a sump at the bottom. Air enters at the bottom of the column and exits through a de-mister at the top. The range of applications of spray columns is limited due to constraints on the liquid throughput and the possibility of fouling at the water injection nozzles.

Typical air to water flow ratios for air strippers range from 25:1 to 75:1 as determined by the specific design of the unit. Steam can also be injected into the column concurrently with air to increase contaminant removal efficiency. This increase in efficiency is the result of the increase in the vapor pressure of the contaminants that occurs when the temperature of the water is raised.

PERFORMANCE:

Performance data for lab-, pilot-, and full-scale applications of air stripping that are relevant to contaminated water from MGP sites are summarized in Table A-1. These data indicate that the VOCs can be effectively removed using air strippers although the concentrations in the treated effluent can be quite variable for similar influent concentrations. Although no data are presented for PAHs, it is reasonable to believe that the removal of naphthalene and other 2-and 3-ring PAHs should be possible whereas the removal of 4-, 5-, and 6-ring PAHs and selected phenolics may be negligible. However, the removal of these contaminants may be achieved, to some degree, with the addition of steam to the stripper.

REFERENCES:

Gas Research Institute, Management of Manufactured Gas Plant Sites Volume IV Site Restoration, Chicago, Illinois, GRI-8710260.4, October 1987.

McCarty, P.L., "Removal of Organic Substances from Water by Air Stripping," in Control of Organic Substances in Water and Wastewater, EPA-600/8-83-011, p. 119-147.

DeRenzo, D. J., Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corp., Park Ridge, N.J., 1978.

Table A-1
PERFORMANCE DATA FOR AIR STRIPPING OF CONTAMINATED WATER

APPLICATION	CHEMICAL	INFLUENT CONCENTRATION (ppb)	EFFLUENT CONCENTRATION (ppb)
FULL-SCALE			
Contaminated Groundwater	Toluene	30.9	0.94
	Ethylbenzene	5.1	0.30
	m,o,p-Xylenes	16.6	0.60
Contaminated Groundwater	Benzene	11	<1(a)
	Ethylbenzene	5	<1(a)
	Toluene	10	<1(a)
	m,o,p-Xylenes	5	<1(a)
Contaminated Groundwater (Gasoline)	Benzene	45000	<50
	Toluene	50000	<50
Contaminated Groundwater (Oil Refinery)	Benzene	1800	<1
	Toluene	1500	<1
	Ethylbenzene	3.6	<1
	Xylenes	80	<1
LAB-SCALE			
Contaminated Groundwater	Benzene	5300	<10
	Toluene	3600	<10
Contaminated Groundwater (Gasoline)	Benzene	11300	1600
	Toluene	37600	7100
	Ethylbenzene	3200	600
	o-Xylene	5100	1000
	p-Xylene	9500	1700
PILOT-SCALE			
Contaminated Groundwater	Benzene	13200	2475
	Ethylbenzene	330	20
	Toluene	13600	2360
	Xylenes	3210	680
Contaminated Groundwater (Gasoline)	Total gasoline compounds	6000-362000	<4

[a] Final effluent from air stripping, multi-media filtering and carbon adsorption processes. (Source: GRI, 1987)

CARBON ADSORPTION

MEDIA:

Contaminated water and vapor.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, all forms of cyanide, and selected metals.

RELEVANT INDUSTRIAL EXPERIENCE:

Extensive lab-, pilot-, and full-scale applications to contaminated water from wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Applications at all scales of development, although more limited in number, have also occurred on contaminated water from MGP sites.

DESCRIPTION:

The adsorption of soluble, aqueous-phase contaminants to activated carbon is the result of the formation of weak chemical bonds that are formed between the contaminant and "active sites" on the surface area of the carbon. The primary driving forces for adsorption from an aqueous phase are a combination of the hydrophobic nature of the contaminant and its affinity to form chemical bonds with the carbon. The adsorption of a specific contaminant will depend on, among other factors, the physical and chemical characteristics of the contaminant, the concentration of the contaminant in the aqueous phase, the bulk characteristics of the aqueous phase, (e.g., the type and concentrations of other contaminants in solution), the properties of the activated carbon and the contact time between the aqueous phase and the carbon.

A schematic of a carbon adsorption process for aqueous phase treatment is presented in Figure A-4. Contaminated water is typically pumped to a holding tank to provide a uniform flow and composition into the carbon absorber. The influent water is pumped continuously from the holding tank, through a filter, to the carbon absorbers. Dual carbon beds are used to provide flexibility during the replacement of the carbon and to ensure that a high effluent quality is achieved. The two columns are operated with one as the lead column and the other as the polish column. This operation permits the lead column to achieve its maximum loading of contaminants, and hence minimize the consumption of carbon, while the polish column minimizes the risk of a breakthrough of contaminants from the treatment system. When the lead column is exhausted (as determined from the monitoring the effluent for selected pollutants), it is taken off line, the polish column becomes the lead column, and the carbon in the original lead column is regenerated in-place or replaced with virgin carbon. This column then becomes the polish column in the dual bed system. The normal flow pattern for this mode of operation is shown in Figure A-4.

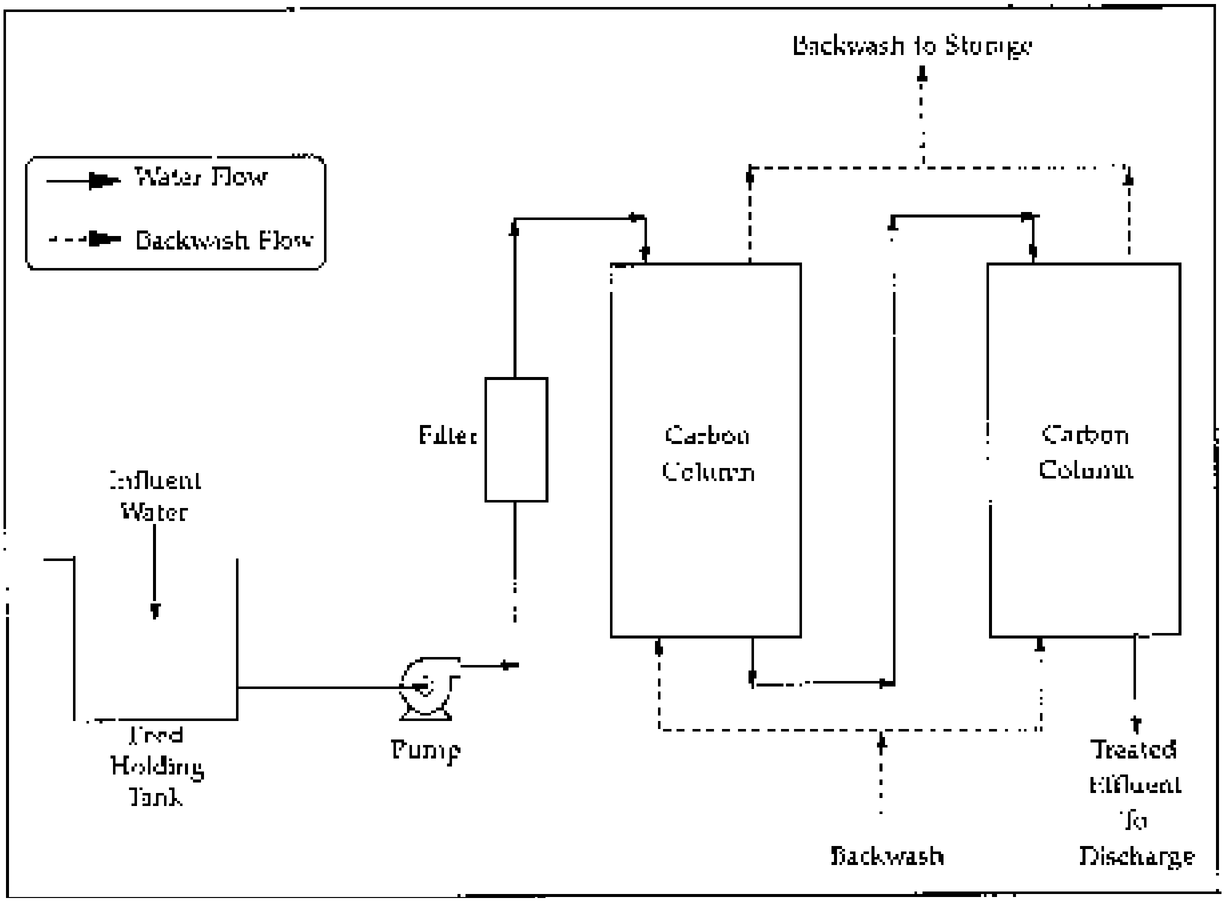


Figure A-4. Process Flowsheet for Aqueous Phase Carbon Adsorption.

Treated effluent from the absorbers is typically discharged directly although an effluent storage system may be required to permit monitoring of the treated effluent prior to discharge. A more cost-effective approach to temporary storage and monitoring prior to discharge may be to monitor the discharge from the lead column on a regular basis and to use this information to determine compliance with discharge requirements, understanding that the actual effluent quality will be better than that which is measured from the lead column due to the presence of the polishing column. This mode of operation, however, may result in the premature regeneration or replacement of the carbon in the lead column which may negate any cost savings that result from eliminating the need for final storage and monitoring.

It is critical that total suspended solids be removed prior to carbon adsorption to prevent fouling and plugging of the columns. Specific to groundwater, the concentrations of reduced manganese and iron should be reduced to less than 1 to 5 mg/L to prevent their precipitation in the carbon column. The removal of manganese and iron is usually achieved by precipitation followed by gravity settling.

The carbon adsorption of vapor phase contaminants typically involves routing the vapor through adsorption columns that contain activated carbon. The contaminants are adsorbed to the carbon surface, purifying the vapor as it passes through the unit. An example of a vapor phase carbon adsorption system is shown in Figure A-5. These systems are commonly used to treat the offgases from air strippers or from vapor extraction wells which are installed as part of an *in situ air* stripping process. If the carbon cannot be regenerated in place, two or more adsorption columns are used in series. The contaminated vapor is passed through one unit until its adsorption capacity is exhausted as indicated by the detection of contaminants in the discharge. The contaminated vapor is then directed to the second unit while the carbon in the first unit is replaced with fresh carbon. This spent carbon can be sent to a reprocessing facility for high temperature regeneration or disposal. If the carbon can be regenerated in-place, steam is passed through the column to heat the carbon to approximately 210°F. The contaminants are desorbed from the carbon and are carried from the system with the steam, which is subsequently condensed and collected for disposal or reuse.

PERFORMANCE:

Carbon adsorption has been used to treat contaminated water and vapor at a number of remediation sites. Performance data for lab-, pilot-, and full-scale applications to contaminated waters for a number of sites that are relevant to MGP sites is summarized in the literature. Most of the literature data emphasize the treatment of VOCs and phenol although selected data are provided for PAHs. The pilot- and full-scale applications routinely report effluent concentrations of 100 ppb or less for these contaminants. More variation is seen in the lab scale data although this would be expected given that the objectives of lab-scale studies is to investigate a wide range of operating conditions. In most cases, the extremely low effluent concentrations (i.e., 10 ppb or less) were achieved using two carbon columns in-series.

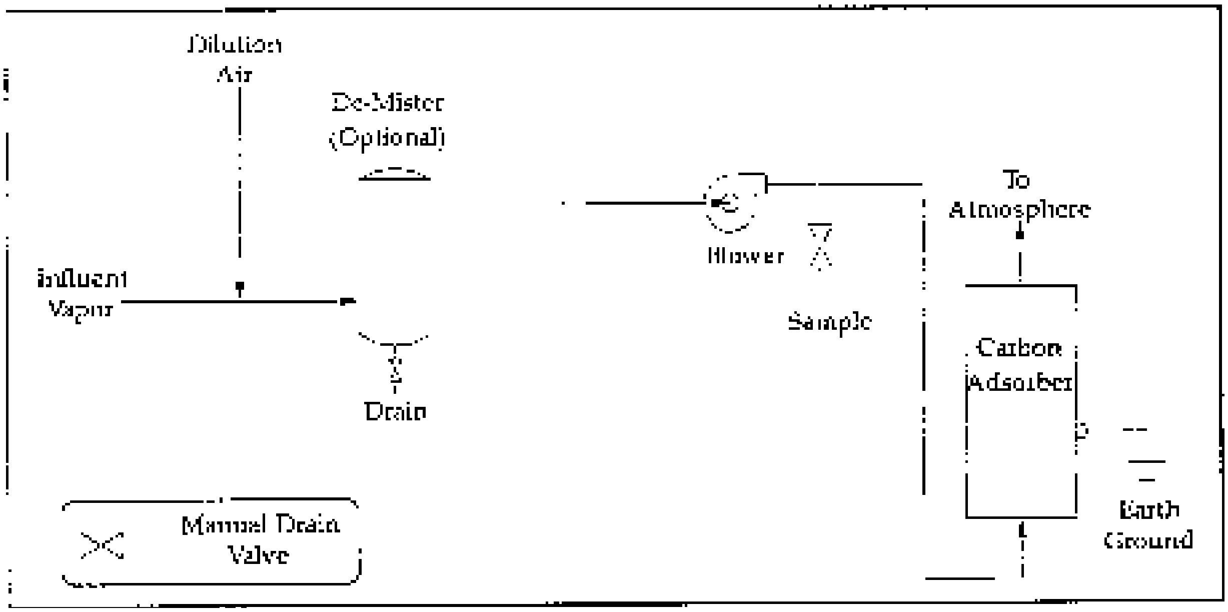


Figure A-5. Process Flowsheet for Vapor Phase Carbon Adsorption.

REFERENCES:

Aerojet-General Corporation, "Aerojet General Tests Activated Carbon for Removal of Volatile Organics From Ground Water", The Hazardous Waste Consultant, September/October, 1985, pp. 1-26 through 1-29.

Gas Research Institute, Management of Manufactured Gas Plant Sites - Volume IV Site Restoration., Chicago, Illinois, GRI-87/0260.4, October, 1987.

Walters, R. W. and R. G. Luthy, "Equilibrium Adsorption of Polycyclic Aromatic Hydrocarbons from Water onto Activated Carbon", Environmental Science and Technology., Vol. 18, No. 6, 1984, pp. 395-403.

Calgon Corporation marketing literature; Pittsburgh, PA.

CHEMICAL COAGULATION/FLOCCULATION

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

Insoluble colloidal matter including solids and suspended phase oil and tars.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-scale, pilot-scale and full-scale applications to contaminated water from wood treating, coal-tar distillation, petroleum refining, and coke manufacturing. Lab- and pilot-scale applications only to contaminated water from manufactured gas plant sites.

DESCRIPTION:

Coagulation and flocculation are processes that are designed for the removal of suspended colloidal matter. Colloidal matter has an approximate size range of 0.001 to 1 micrometers and cannot be removed from the water by gravity settling. Two types of colloidal matter, hydrophobic and hydrophilic,' may exist in solution. Hydrophobic colloidal matter has no affinity for water and are susceptible to coagulation and flocculation. Hydrophilic colloidal matter, however, possess an affinity toward water and are more resistant to coagulation and flocculation.

The small size and electrical properties of the colloidal matter prevent their removal by gravity settling. As individual particles, they do not possess sufficient mass to overcome the buoyant forces of the water. Furthermore, the repelling forces of the matter are too great to be overcome by the attracting Van der Waal forces, thereby preventing these materials from naturally coalescing to form larger, settleable particles. As such, the addition of coagulants is required to decrease the repelling forces and to cause the matter to aggregate. Aggregation is accomplished during a slow mixing step where the probability of interparticle collisions is high. Typical coagulants include polyelectrolytes and polymers and can be cationic, anionic, or nonionic. A typical coagulation-flocculation unit is shown in Figure A-6.

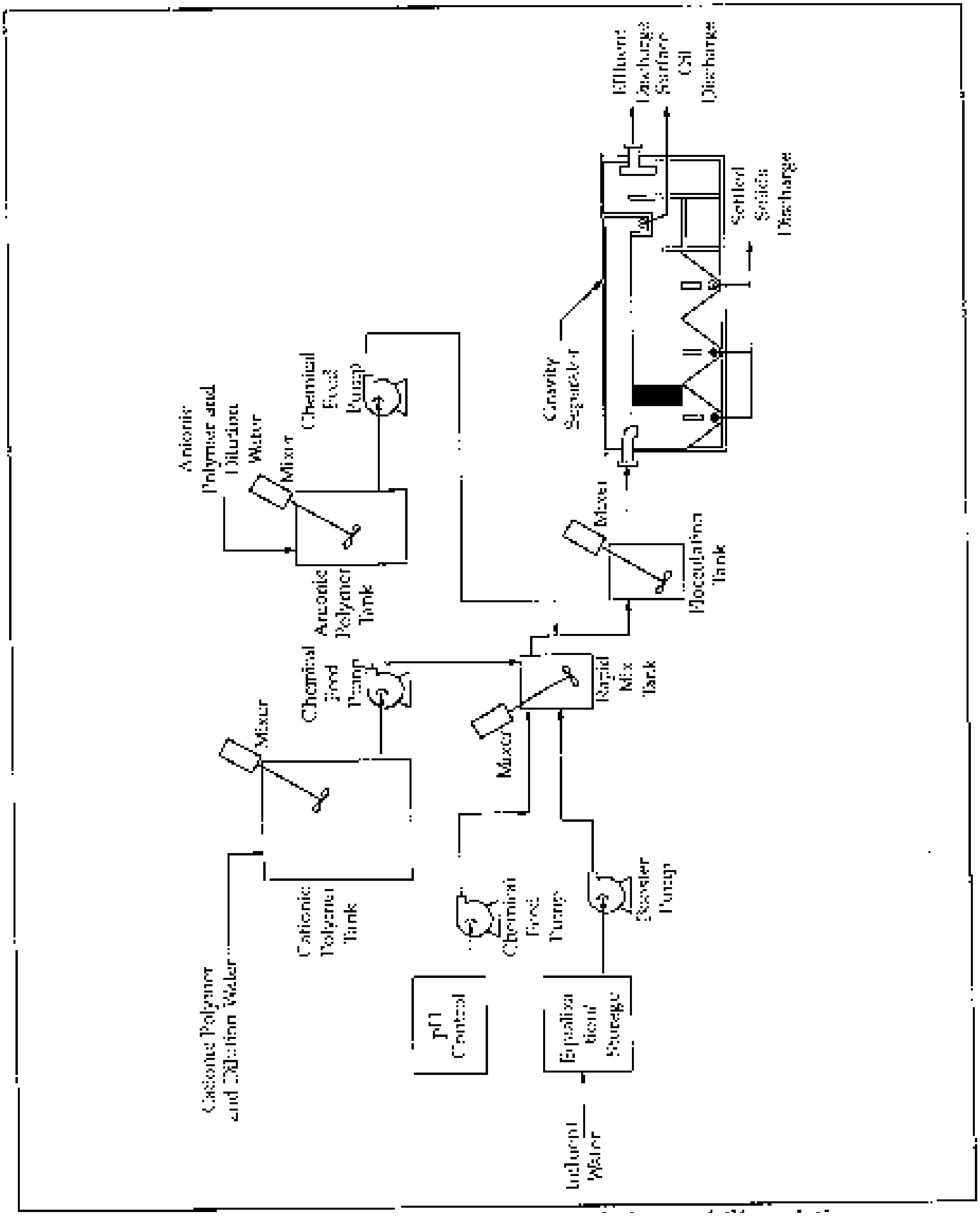


Figure A-6. Process Flowsheet for Chemical Coagulation and Flocculation.

Flocculation is accomplished using organic compounds similar to those used in coagulation. Inorganic flocculants include alum, lime, and iron salts. Upon dissolution, the flocculants form fluffy, gelatinous particles or flocs. Due to their large surface area, these flocs are able to capture the colloidal matter. Once the flocculation step is completed, floc with the colloidal matter is removed. This removal can be achieved by simple gravity separation provided the floc is sufficiently dense. Flocculation is less effective in highly viscous liquids which inhibit the gravity settling of the flocs.

PERFORMANCE:

Commercial applications of coagulation and flocculation have occurred in several industry categories. The performance in these applications is very sensitive to the chemical and physical characteristics of the water. However, as an indication of the extent of treatment that has been achieved, there are reports of industrial laundry wastes that have been successfully treated using sulfuric acid, lime, and alum. In this instance, the chemical oxygen demand was reduced from 12,000 to 1,800 mg/L and the total suspended solids were reduced from 1,620 to 105 mg/L. In another case, a polymer waste from a latex manufacturer was treated with ferric chloride and lime and resulted in a 75% and 94% reduction in the chemical oxygen demand and biological oxygen demand, respectively.

Given the importance of the water quality on the effectiveness of coagulation and flocculation, it is imperative that simple laboratory treatability tests be conducted to properly choose the chemicals for use and to determine the optimal quantities of each chemical that is required to achieve effective treatment of the water.

REFERENCES:

Rich, Gerald and Kenneth Cherry; Hazardous Waste Treatment Technologies; ISBN 0-934165-11-9.

Eckenfelder, W. Wesley, Jr.; Industrial Waste Pollution Control; ISBN 0-07-018903-X.

CHEMICAL OXIDATION

MEDIA:

Contaminated soil, sediment, and water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, selected metals, free/weak-acid dissociable cyanide, and conventional pollutants such as COD, BOD, and TOC.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated water from wood treating, coal-tar distillation, and coke manufacturing industries. Lab- and pilot-scale studies have been conducted on contaminated soil and water from MGP sites.

DESCRIPTION:

Chemical oxidation is a process which alters the oxidation state of an undesirable chemical species and converts it to a species which is neither harmful nor otherwise objectionable. The most common oxidants for organic contaminants are chlorine, chlorine dioxide, ozone, and hydrogen peroxide while potassium permanganate is often used specifically to oxidize metals such as iron and manganese.

Chlorination processes use chlorine gas, chlorine dioxide gas, or a salt of hypochlorous acid such as calcium hypochlorite or sodium hypochlorite as the oxidant. The active species is the same regardless of the parent chemical, but the properties of the aqueous chlorine solution that is used will vary somewhat based upon the source of chlorine. For example, aqueous solutions of chlorine dioxide (CLO_2), which is a highly unstable gas, are more stable than the gas but still decompose rapidly and must be made on site. Hydrogen peroxide is also utilized in an aqueous solution for chemical oxidation. A 35 percent solution is available commercially and is used full-strength or diluted, depending on the specific application. Lastly, ozone, which is also an unstable gaseous compound, is used to oxidize contaminants in water. Ozone is produced through the discharge of an electric current across an air stream that contains oxygen. The ozone enriched gas is then contacted with the contaminated water.

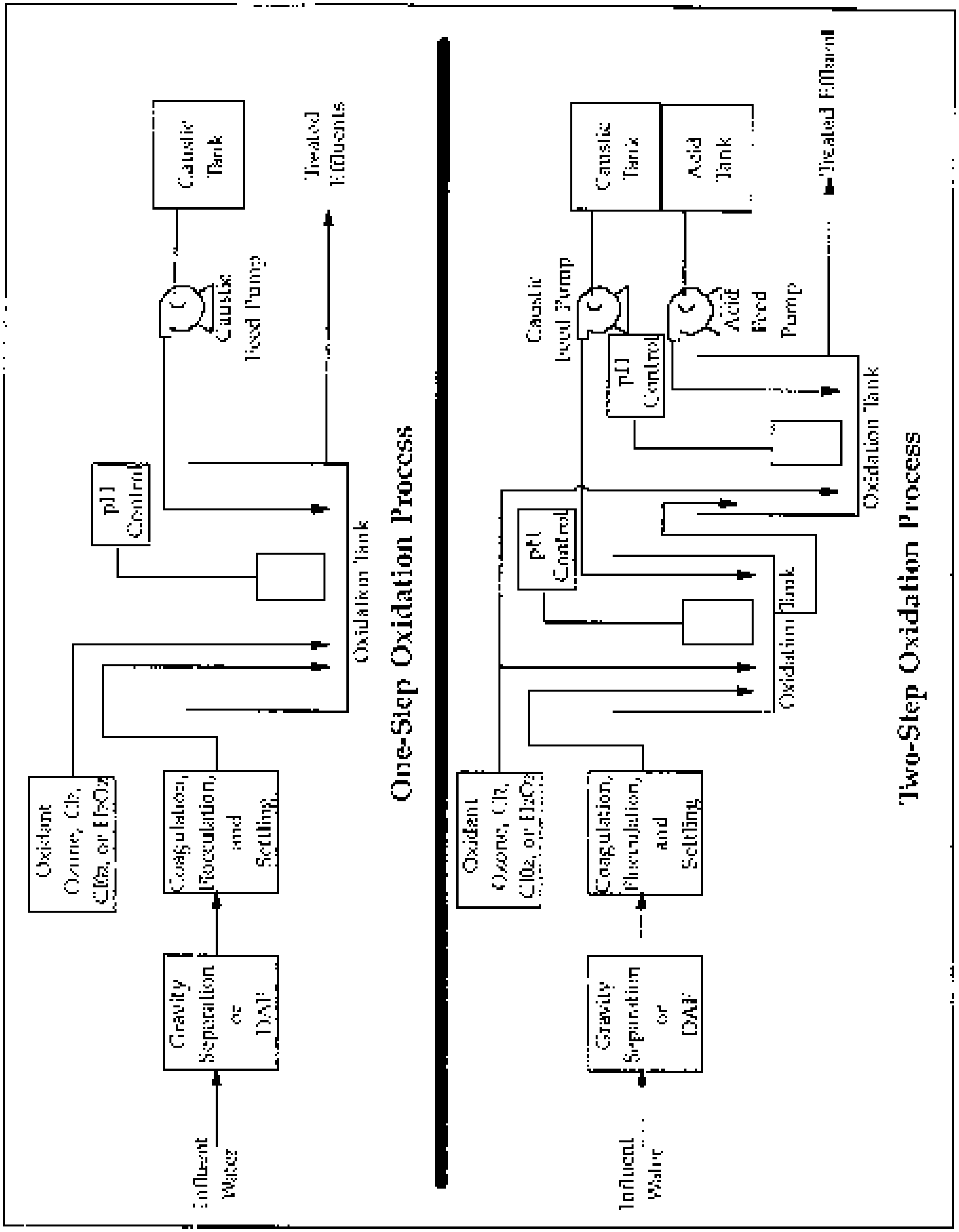


Figure A-7. Process Flowsheet for Chemical Oxidation.

Figure A-7 presents two possible treatment schemes for chemical oxidation of a contaminated water. A one-step process is depicted in the upper portion of the figure while a two-step process is shown in the bottom portion. The two-step process consists of oxidation at a high pH followed by further oxidation at a lower pH. For both treatment schemes, the retention time in the reaction tank(s) and the oxidant dosages vary with the composition of the water. Theoretical considerations and treatability study results are used to establish the process design, oxidants, oxidant dosage, and retention time that are needed to properly treat a specific media.

The treatment of contaminated solids using chemical oxidation requires that the solid be combined with water to form a liquid/solid slurry (usually no greater than 20% by weight solid). The oxidant is then added to this mixture. It is presumed that most of the oxidation reactions occur in the aqueous phase and, hence, are identical to those that occur during the treatment of contaminated water. While it is possible that some reactions occur directly between the oxidant and the soft-bound contaminants, this mechanism of contaminant destruction has not been verified. As such, the extent of contaminant reduction that can be achieved is largely limited by the mass transfer of the soilbound contaminants to the aqueous phase. Hydrogen peroxide is the most common oxidant that is used to treat solids. This is due to its relative stability compared to other oxidants. More recent studies have combined iron sulfate with the hydrogen peroxide (otherwise known as Fenton's Reagent) as a means to enhance the treatment that is achieved by hydrogen peroxide alone.

PERFORMANCE:

The ability of chemical oxidation to oxidize VOCs, PAHs, phenolics, and free/weak-acid dissociable cyanide has been demonstrated. Substantial percentage reductions can be achieved (e.g., greater than 95 percent) providing that the appropriate dose of the oxidant is used and that sufficient mixing and contacting of the oxidant and contaminant occurs. Excessive doses of the oxidant may be required to achieve the treatment of the target contaminants if other chemicals that are present in the water also react with the oxidant. In these instances, it may be prudent to pretreat the influent water to minimize these extraneous reactions and the excess consumption of the oxidant.

Reductions of the target contaminants in soils has also been observed but not to the extent reported for contaminated water. This difference is attributable to the additional step of contaminant desorption from the solid to the aqueous phase which must occur before the oxidation reactions can take place. Nevertheless, recent claims have been made that the combination of Fenton's Reagent treatment combined with biological treatment can achieve reductions in total PAHs of greater than 90 percent. Similar data have been reported from field demonstration tests. An analysis of these data to determine the relative roles of chemical and biological oxidation in the removal of the PAHs is still underway.

REFERENCES:

DeRenzo, D. J., *Unit Operations for Treatment of Hazardous Industrial Wastes,* Noyes Data Corporation, Park Ridge, New Jersey, 1978.

Gas Research Institute, *Management of Manufactured Gas Plant Sites - Volume IV: Site Restoration.* Chicago, IL, GRI-87/0260.4, October, 1987.

Institute of Gas Technology, Internal Data Base, Chicago, IL, 1990.

DISSOLVED AIR FLOTATION

MEDIA:

Contaminated water

TARGET CONTAMINANTS:

Insoluble material including solids and suspended phase oil and tars.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated water from wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries.

DESCRIPTION:

Dissolved air flotation (DAF) is generally used on contaminated water where the specific gravity of the suspended material is very close to that of water. As such, these particles gravity settle very slowly or not at all. The use of DAF permits the more effective removal of these materials in a shorter time period.

Separation is achieved in the DAF process by introducing fine gas (usually air) bubbles into the liquid phase. The bubbles attach to the suspended matter and the buoyant forces of the combined particle and gas bubble is great enough. to cause it to rise to the surface. Once the matter has been floated to the surface, it can be collected by mechanical skimmers.

Air bubbles are introduced to the DAF unit in two different ways. The first and most common method is by pressurizing the water with air, then releasing it to the atmosphere in the flotation tank (pressure flotation). The other method is less common but produces the same results, and involves decreasing the pressure in the flotation unit through the application of a vacuum. This releases the gases that are naturally dissolved in the water.

Two variations of pressure flotation exist: direct and effluent recycle. The direct DAF process subjects the water and suspended matter to the high shear forces of the pressurizing pump and the pressure release valve. This method is generally used for separating suspended phase oil and tars from contaminated water. Effluent recycle is the more common method of dissolved air flotation. It is used when the suspended matter forms a fragile floc.

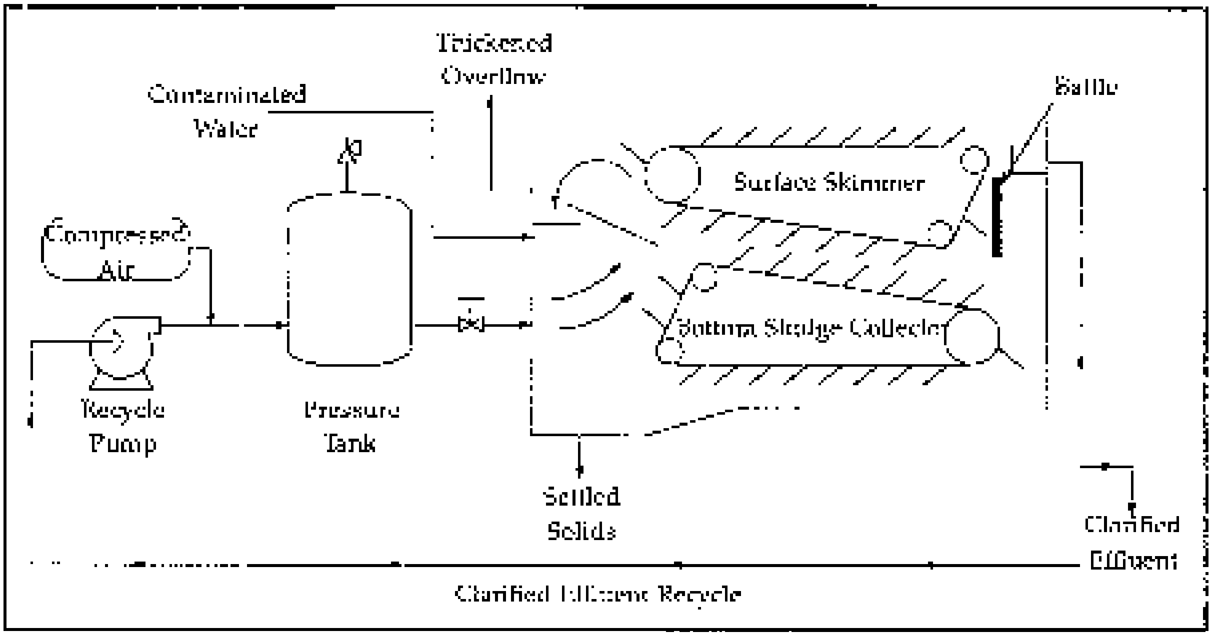


Figure A-8. Process Flowsheet for Dissolved Air Flotation Unit.

This type of floc is usually formed when coagulants and flocculants are used to enhance separation.

A process flowsheet of an effluent recycle DAF process is shown in Figure A-8. The contaminated water enters the flotation tank with the pressurized recycle. The escaping air bubbles attach to the suspended matter which rises to the surface and compacts. This surface accumulation is removed and recycled/reused or managed as a waste. The dense solids that do settle to the bottom of the tank, are also removed and appropriately managed. The clarified effluent is removed and is discharged, reused, or subjected to additional treatment. A portion of the clarified effluent is pressurized and recycled to the DAF unit.

PERFORMANCE:

Dissolved air flotation has been demonstrated for the removal of suspended matter from contaminated water. The removal of suspended matter results in the reduction of contaminant concentrations for total suspended solids and oil and grease. Removal of other contaminants, such as total organic carbon and PAHs, also occurs simultaneously. The extent of the removal of these other contaminants is dependent upon their association with the suspended matter, e.g., the contribution of suspended colloidal solids to total organic carbon or PAH concentrations in the water. A properly designed and operated DAF unit can generally achieve:

- 60 to 95 percent removal of oil & grease, and

- 80 to 98 percent removal of total suspended solids.

A pilot-scale test of a DAF unit was conducted at an MGP site in Maryland. The unit treated 15 to 20 gpm of groundwater and was the initial treatment step of a process train that also involved a fluidized bed biological reactor, carbon adsorption, and cyanide treatment.

REFERENCES:

Gas Research Institute, *Management of Manufactured Gas Plant Sites - Volume IV: Site Restoration,* Chicago, IL, GRI-87/0260.4, October, *1987.*

Metcalf and Eddy, Inc. *Wastewater Engineering Treatment/Disposal/Reuse,* McGraw Hill Book Co., New York, NY, 1979.

FLUIDIZED BED BIOLOGICAL TREATMENT

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, ammonia, and conventional pollutants such as BOD, COD, TOC, and total suspended solids.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated water from wood treating, coal-tar distillation, and coke manufacturing industries. Several lab-and pilot-scale studies have been conducted on contaminated water from MGP sites and two demonstration tests are planned at MGP sites in 1994.

DESCRIPTION:

Fluidized bed biological treatment of contaminated water occurs by passing it through a suspended bed of material, such as sand, coal, or activated carbon, upon which a microbial film has developed. The active biomass biologically degrades the contaminants in the water. When activated carbon is used as the fluidized media, the process of adsorption followed by biodegradation of the adsorbed contaminants occurs, achieving nondetectable organic contaminant concentrations in the treated effluent. As the contaminants are biodegraded, the activated carbon is regenerated and once again becomes an effective adsorbent.

A fluidized bed biological reactor utilizes the same biology and chemistry as the activated sludge biological treatment systems. The success of the process is attributed to the very high concentration of microorganisms that are maintained within the reactor. In addition, the presence of activated carbon offers the additional benefit of providing a treatment system that can withstand shock loadings and/or large swings in influent water quality. Multiple fluidized bed reactors can be operated in series to perform both aerobic and anaerobic biodegradation of contaminants. Figure A-9 represents a typical process flowsheet for a fluidized bed reactor treatment system.

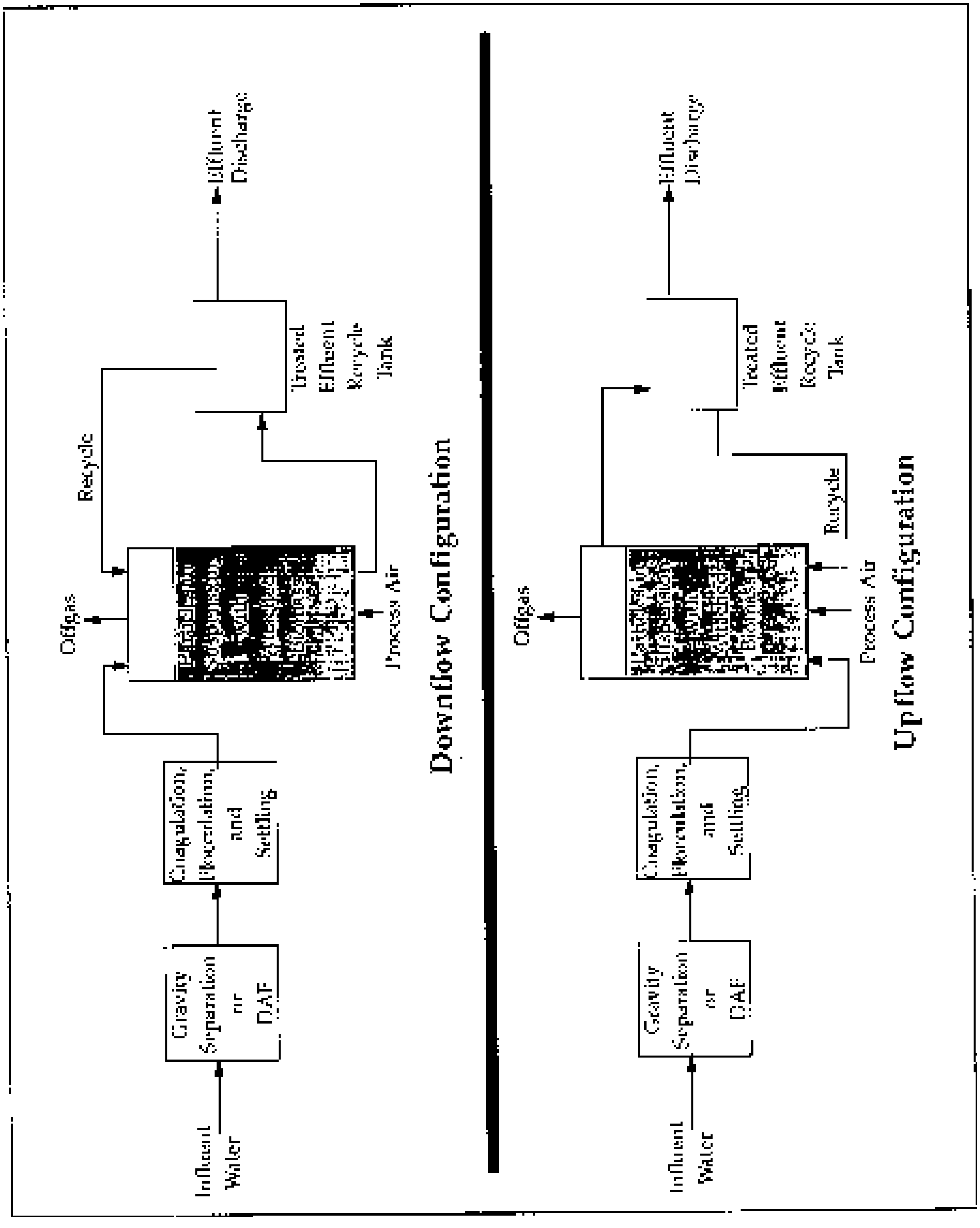


Figure A-9. Process Flowsheet for a Fluidized Bed Biological Treatment System.

PERFORMANCE:

Fluidized bed biological treatment is a proven technology for the removal of biodegradable compounds found in domestic and industrial wastewaters. A properly designed and operated fluidized bed treatment process can generally achieve the following percentage reductions in contaminants:

- greater than 99 percent of phenolics and thiocyanate,
- between 90 and 99+ percent of ammonia nitrogen and nitrate nitrogen,
- between 80 and *99*+ percent of total organic carbon, and
- between 95 and 99+ percent of VOCs.

Specific applications of this physical/biological treatment process to contaminated water from MGP sites have recently been completed. These studies have demonstrated the technical ability of the process to remove PAHs from contaminated water. Specific reductions of PAHs which have been observed in these studies are as follows:

- 2- to 4-ring PAHs: >99.5%
- 5- and 6-ring PAHs: 60 to 80%

Two full-scale demonstrations of this process will be completed at MGP sites in 1994 and will provide both performance and economic data for use by the utility industry.

REFERENCES:

Barbara, M., F. Flood, and J. Jesus, "Fluidized Beds Improve Treatment, Cut Costs," *Wastewater Treatment,* June, 1980.

Gas Research Institute, Management of Manufactured Gas Plant Sites - Volume IV: Site Restoration. Chicago, IL, GRI-87/0260.4, October, 1987.

Gas Research Institute, *An* Application of Biological Granular Activated Carbon Fluidized Bed Reactor Process for Gas Industry Wastes, GRI-93/0352, Chicago, IL, September, 1993.

Gas Research Institute, "Additional Data from the Treatment of Groundwater in a Fluidized Bed Bioreactor," *MGP Update,* Chicago, IL, pp. 14-15, July, 1993.

GRAVITY SEPARATION

MEDIA:

Contaminated water

TARGET CONTAMINANTS:

Insoluble material including solids and suspended phase oils and tars.

RELEVANT INDUSTRIAL EXPERIENCE:

Several applications to contaminated water from wood treating, coal-tar distillation, coke manufacturing, and petroleum refining, and chemical manufacturing industries. Limited applications to contaminated water from MGP sites.

DESCRIPTION:

Gravity separation is the process of removing insoluble materials from water via natural differences in specific gravity (i.e., materials with a lower specific gravity than water will float while those with a higher specific gravity will sink). The separation process for removal of emulsified oils can be enhanced by the addition of chemicals (i.e., chemical coagulation and flocculation) either prior to or after gravity separation.

Typically, gravity separation, as shown in Figure A-10, is the first operation in a water treatment system. The incoming water is passed through a series' of chambers where the removal of insoluble materials occurs by impingement on strategically placed baffles and by settling during a quiescent period that is provided in each chamber. Insoluble materials that are less dense than water rise to the surface of the chambers and are removed by a surface skimmer or pumped from the water interface while the settleable materials (i.e., those with a density greater than water) are drained or scraped from the bottom of the separator. Following separation, the water can be discharged, reused, or receive additional treatment. The insoluble material can be recovered and recycled or managed as a waste.

Finely suspended colloids or hydrocarbon/water emulsions cannot be removed using gravity separators alone. The presence of these contaminant forms usually requires the addition of chemicals and other additives either prior to or after gravity separation. (See Chemical Coagulation and Flocculation.)

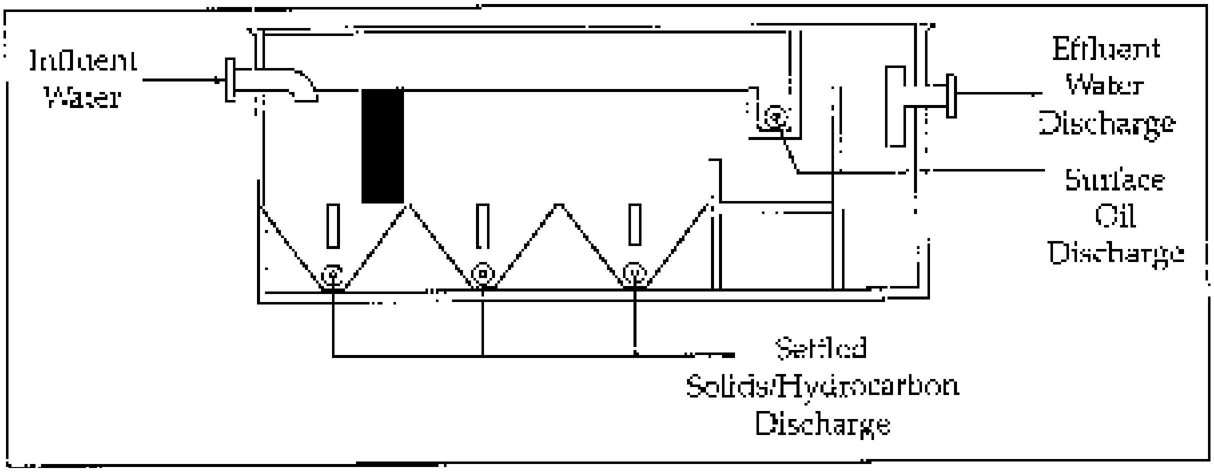


Figure A-10. Process Flowsheet for Gravity Separator.

PERFORMANCE:

Gravity separation has been demonstrated for the removal of suspended insoluble matter and oil & grease. PAH reduction is achieved concurrently through its association with the oil & grease and suspended solids. For similar reasons, a reduction in total organic carbon is also achieved. Existing physical/chemical separation systems have been shown to achieve:

- Oil & grease and suspended solids reductions as high as 90 percent, and
- Total PAH reductions as high as 80 percent.

It should be cautioned, however, that the percentage reduction in PAHs will be a strong function of their initial distribution in the contaminated water. For example, the percentage removal will be greater as the distribution of PAHs shifts to the 5- and 6-ring compounds since it is these compounds that are most hydrophobic and that tend to associate with the hydrocarbon and solid phase materials. On the other hand, percentage removals will decline as the PAH distribution becomes dominated by the 2-, 3-, and 4-ring compounds.

REFERENCES:

Brunsmann, J. J., J. Cornelissen, and H. Eilers, "Improved Oil Separation in Gravity Separators," Water Pollution Control Federation Journal, 1962.

Gas Research Institute, Management of Manufactured Gas Plant Sites - Volume IV.' Site Restoration, Chicago, IL, GRI-87/0260.4, October, 1987.

ION EXCHANGE

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

All inorganic cations, (e.g., heavy metals and ammonia), inorganic anions (e.g., cyanide), and ionic organic compounds (e.g., phenolics).

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated water from the petroleum refining, coal-tar distillation, and wood treating industries.

DESCRIPTION:

Ion exchange is a separation process which removes ions of contaminants from an aqueous solution by exchanging them with ions that are present on the surface of an ion exchange resin. In practice, ion exchange resins consist of "beads" that are placed in a column. Contaminated water is passed through the bed where the exchange of ions occurs. Natural ion-exchange materials (zeolites) exist; however, most industrial applications uses synthetic resins which consist of high-molecular-weight organic polymers onto which chemical functional groups (e.g., sulfuric, carboxylic, phenolic, aminos) have been added.

A process schematic of an ion exchange treatment process is presented in Figure A-11. The system normally includes a storage tank prior to the ion exchange columns to equalize the influent water flow rate and to permit the gravity settling of coarse solids. The untreated water is pumped from the storage tank directly to the ion exchange columns. Pretreatment such as filtration or carbon adsorption is often required for contaminated water to extend the life of the resin. Treated water flows by gravity from the columns to an effluent storage tank to allow for monitoring prior to discharge. Conductivity, which is a measure of total ion concentration, can be used to determine when the resin in a specific column is exhausted.

If large volumes of water are treated, two columns may be required to provide uninterrupted operation during periods of resin regeneration. For example, the influent water is treated in one column until the resin in that column is exhausted. At that time, the water flow can be switched to the second column while the spent resin is regenerated in the first.

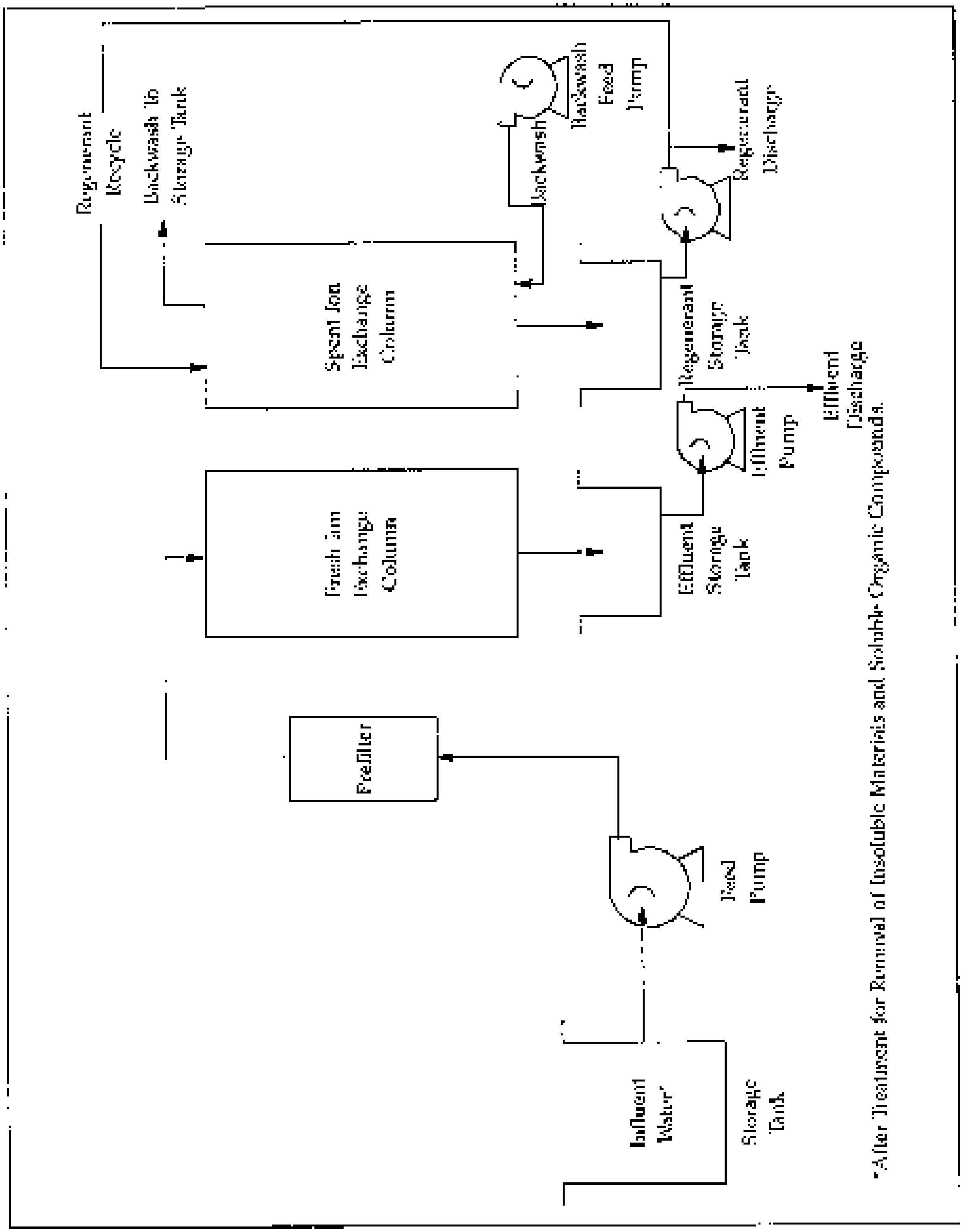


Figure A-11. Process Flowsheet for Ion Exchange System.

After regeneration, the first column would sit idle until the resin in the second column was spent, at which time the water flow would be switched to the first column and the cycle would be repeated.

With the mixed bed scheme, the regeneration of the ion exchange resin employs a special operating sequence. The resin bed is first backwashed (i.e., water is pumped through the column in a direction that is opposite the flow of the influent water) gently with water to remove suspended solids after which the flow rate is increased until the bed is fluidized. Dilute hydrochloric acid is then pumped through the column in the same direction as the flow of the contaminated water. Following the acid, the column is then washed with water and a dilute sodium hydroxide. After another water wash, the column is returned to service. The various acid, caustic, and water wash solutions contain varying concentrations of contaminants and must be properly managed. The methods of regeneration and types of regenerate solutions vary according to the type of ion exchange 'resin that is utilized in the process. It should be noted that there are ion exchange resins available which are not regenerable and thus have to be replaced after they are spent. In these instances, the cost of resin replacement and disposal are incurred in lieu of the management costs associated with the various regenerants.

PERFORMANCE:

Ion exchange resins can theoretically remove all ionic contaminants provided that the proper resin has been selected and that adequate contact time between the water and resin is provided. Industrial experience has demonstrated that metal concentrations of 50 to 100 ppb can be achieved in the treated effluent. Lab-scale tests have yielded even lower concentrations of metals in the treated effluent (i.e., 10 ppb). However, treatment efficiency can vary significantly with each application since the competition among contaminants for available resin sites may occur causing less than expected contaminant removal and/or resin exhaustion before it is anticipated.

Ion exchange applications to contaminated water from inactive industrial sites have not been identified. Most performance data that have been reported are for plating process wastes which have high concentrations of dissolved metals. Another application was in an oil refinery where contaminant concentrations in a condensate were reduced to <3 ppm hydrogen sulfide, 5 ppm ammonia, and 20 ppm phenol.

It must be emphasized that the performance of an ion exchange process is very dependent on the composition of the contaminated water that is targeted for treatment.

REFERENCES:

Dow Chemical Company, *Water Conditioning Manual,* DOWEX Ion Exchange Resin, 1985.

Gas Research Institute, *Management of Manufactured Gas Plant Sites–Volume IV: Site Restoration.* Chicago, IL, GRI-87/0260.4, October, 1987.

Lefevre, L. J., "Ion Exchange: Problem and Troubleshooting," *Groundwater Pollution Control,* Lewis Publishers, Chapter 3, pp. 89-125, 1985.

NEUTRALIZATION

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

pH.

RELEVANT INDUSTRIAL EXPERIENCE:

Widely used in numerous industries including wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing. Extensive applications to contaminated water from MGP sites in lab- and pilot-scale studies with limited full-scale applications.

DESCRIPTION:

Neutralization is the process of adding an acid (low pH) or a base (high pH) to a liquid to alter its pH to neutral conditions (i.e., pH between 6 and 8). The choice of a neutralizing agent, i.e., acid or base, is generally an economic one which considers the purchase cost as well as its compatibility with the contaminated water and the process equipment. The neutralization step can be implemented using either continuous or batch processes. The batch process allows for the greatest control because the pH of the batch can be monitored and the discharge delayed until the proper pH is attained. Unfortunately, because' of storage requirements, the batch process is normally limited to contaminated water with low flow rates. For medium to high flow rates, some form of a continuous process is used which generally requires more elaborate control and chemical feed equipment. Figure A-12 illustrates a typical multiple unit, continuous flow neutralization process which includes: pH monitor(s), mixer(s), tanks, and chemical feed equipment.

Contaminated waters whose pH can change rapidly (i.e., the water is unbuffered) may require the use of an equalization basin or multiple neutralization units. The equalization basin dampens the pH fluctuations by incorporating the water flow into large volumes of water prior to further processing. Multiple neutralizing units adjust the pH of the water on a frequent basis in response to pH changes that occur during its treatment.

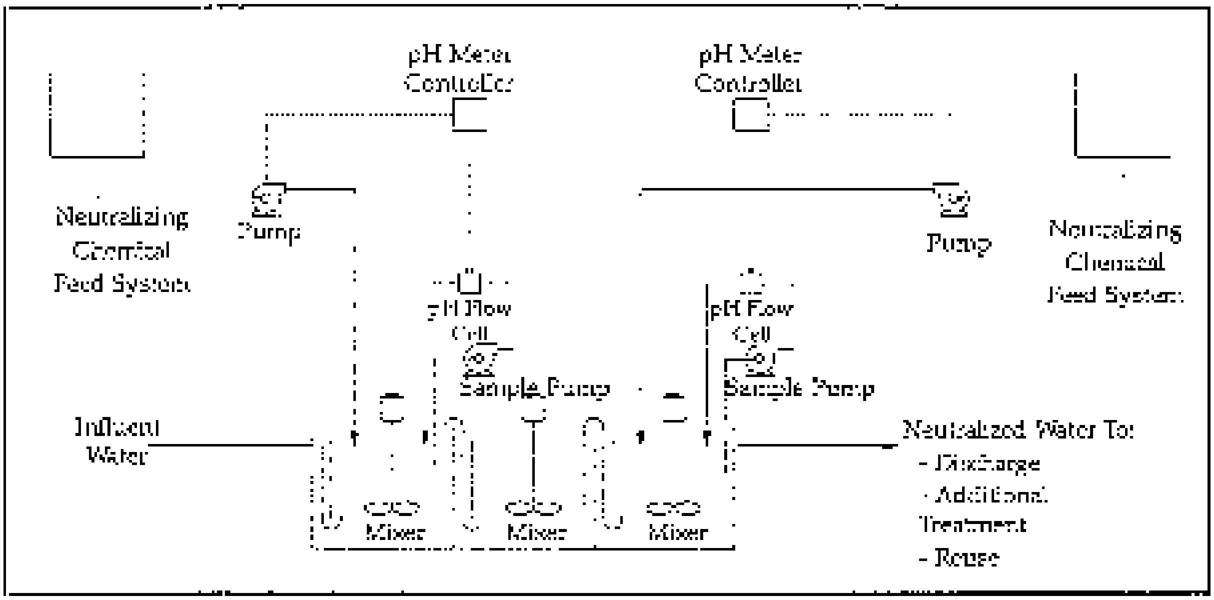


Figure A-12. Process Flowsheet for Neutralization.

Neutralization costs can be minimized by strategically mixing acidic and alkaline waters to achieve the required pH adjustments. However, this type of mixing should be done with caution since the formation of products from the reactions of contaminants in the two waters can lead to more difficult treatment problems. Similarly, any pH adjustment should be done with care since neutralization is an exothermic reaction and, as such, will generate heat. This heat can lead to the release of toxic vapors which can pose a threat to either workers or to the public-at-large. In addition, the alteration of pH inevitably leads to the formation of insoluble precipitates. The management of these precipitates must be factored into the costs for water treatment and should not be ignored.

PERFORMANCE:

There is a substantial amount of data associated with the neutralization of contaminated water; however, little of it can be directly translated to a specific situation at an MGP site. As such, all neutralization steps should be examined using simple lab-scale tests to determine the potential for vapor release, precipitate formation, or other chemical side reactions. It should be noted that some of the reactions that occur during neutralization can result in the reduction of contaminants from the water. For example, many of the dissolved metals may be removed as precipitates during neutralization. Similarly, other contaminants may be volatilized. Most of the contaminants that are influenced by the changes in pH are inorganic contaminants; however, some reductions in organic contaminants may also occur.

REFERENCES:

DeRenzo, D. J., Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corp., Park Ridge, N.J., 1978.

Parsons, W. A., Chemical Treatment of Sewage and Industrial Wastes, Gourmand/Pridemark, Baltimore, MD, 1985.

UV/CHEMICAL OXIDATION

MEDIA:

Contaminated water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, selected metals, all forms of cyanide, and conventional pollutants such as COD, BOD, and TOC.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated water from wood treating, coal-tar distillation, and coke manufacturing industries. Lab-scale application to contaminated water from MGP sites.

DESCRIPTION:

Ultraviolet (UV) light enhances the reactions of contaminants with oxidants such as ozone or hydrogen peroxide. The UV light effect is founded in the basic law of photochemistry which recognizes that chemical compounds undergo chemical or physical changes when ultraviolet light is absorbed. The absorbance of UV light causes a transition of electrons and a subsequent breaking apart of the chemical compound. Once this occurs, the chemical is more susceptible to oxidation by either ozone or hydrogen peroxide. This description offers a very simplified view of the UV/chemical oxidation process, but it should be noted that additional research is presently in progress to better understand and quantify the complex chemistry associated with this treatment process.

A process flowsheet for a UV/chemical oxidation is presented in Figure A-13. In this figure, either ozone or hydrogen peroxide, or both, can be used as the oxidant. The gaseous ozone would be bubbled into the reactor whereas solutions of hydrogen peroxide would be added directly to the reactor using a metering pump. A typical UV reactor consists of several chambers separated by baffles which are designed to provide a tortuous flow pattern for the water. Each chamber is equipped with a number of low pressure ultraviolet lamps. The reactor is usually designed so that there is only a thin layer of liquid exposed to the UV lamps. This ensures complete penetration of the liquid by the UV light and good contact of the light with the contaminants. This process is difficult to apply to soils since the solid particles interfere with the contact of the UV light and the contaminants that are in the solution. In addition, the solids tend to foul the UV lamps which also decreases the effectiveness of the treatment.

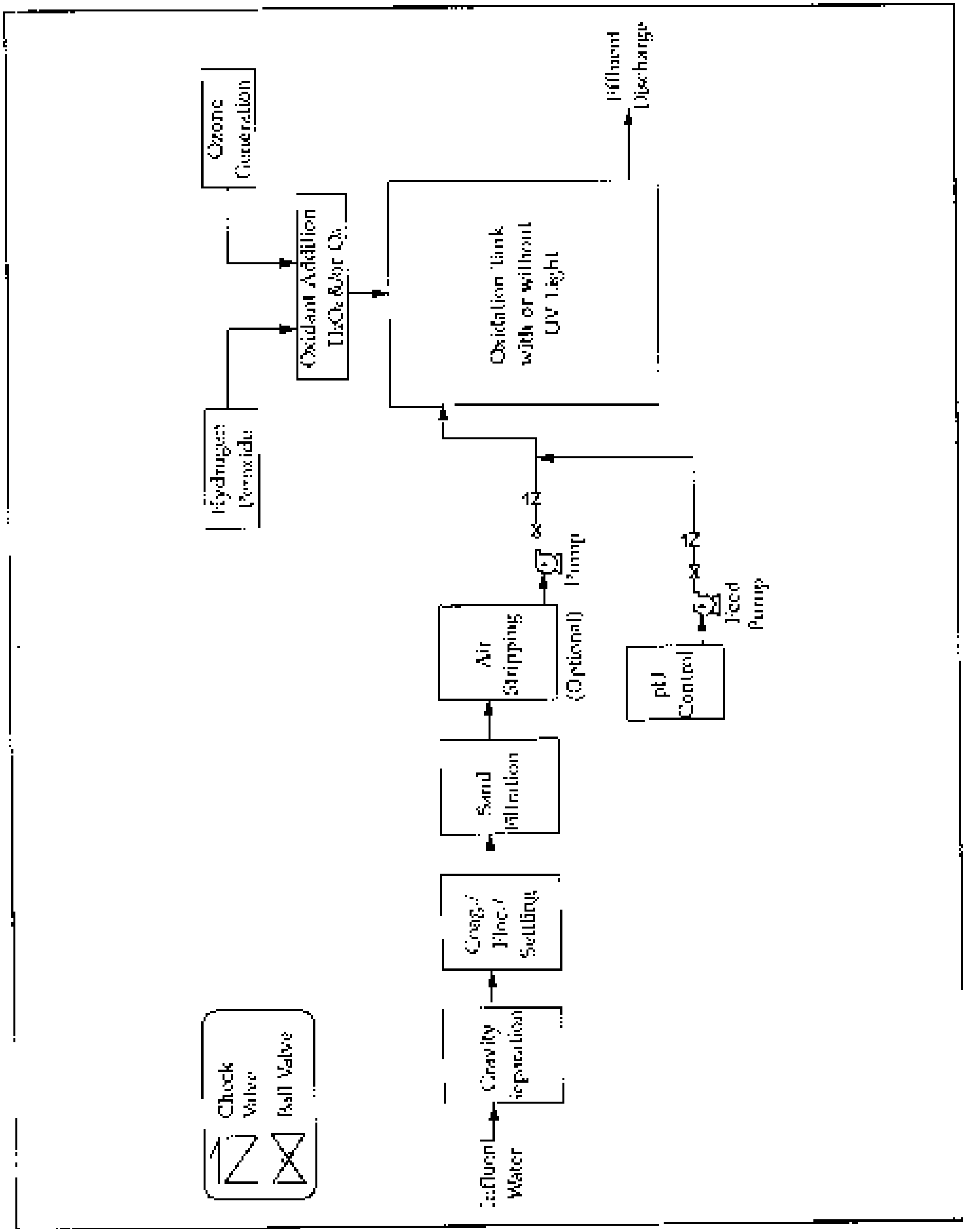


Figure A-13. Process Flowsheet for UV/Chemical Oxidation.

As such, unless the solids are removed from the liquid/solid slurry, UV/chemical oxidation is not readily applicable to the treatment of solids.

PERFORMANCE:

Contaminant removal by UV/chemical oxidation is dependent upon: (i) the oxidant dosage, (ii) the concentration of contaminants, and (iii) their molecular structure. Review of the literature data suggests that there is competition among different chemical groups for the available oxidant and absorbance of UV light which can decrease the treatment effectiveness for the target contaminants. The process effectiveness decreases as the turbidity of the influent water increases.

UV/chemical oxidation of contaminated water with either ozone or hydrogen peroxide has been shown to achieve the following reductions in contaminants:

- between 20 and 90 percent of cyanide.
- between 20 and 99 percent of sulfide.
- between 10 and *99*+ percent of phenolics and
- between 50 and *99*+ percent of PAHs.

The process is well suited for reduction of phenolics, PAHs, and all forms of cyanide. It is important to note that ozone in the presence of UV light has the potential to break the iron-cyanide complex, which cannot be accomplished by most other water treatment technologies.

REFERENCES:

DeRenzo, D. J., Unit Operations for Treatment of Hazardous Industrial Wastes, Noyes Data Corp., Park Ridge, N.J., 1978.

Gas Research Institute, *Management of Manufactured Gas Plant Sites - Volume IV: Site Restoration.* Chicago, IL, GRI-87/0260.4, October, *1987.*

Weber, W., Jr., *Physicochemical Processes for Water Quality Control,* John Wiley & Sons, Inc., New York, NY, 1972.

EX SITU TREATMENT
OF SOURCE MATERIAL AND
CONTAMINATED SOIL AND SEDIMENT

AQUEOUS/SOLVENT EXTRACTION

MEDIA:

Contaminated soil and sediment.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, and selected inorganic contaminants.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab- and pilot-scale applications have been performed on contaminated solids from the wood treating, coke manufacturing, coal-tar distillation, and petroleum refining industries. Limited lab-scale studies have been conducted on contaminated solids from MGP sites.

DESCRIPTION:

Aqueous/solvent extraction technologies separate contaminants from solids primarily through the physical mechanisms of dissolution or leaching. In effect, these technologies concentrate the contaminants in the water or solvent, yielding a treated solid and a contaminated liquid which must be subjected to further treatment or disposal.

Extraction processes represent a physical separation that removes the contaminants from the solid material into an extractant. Typical extractants include: water, alone or with additives such as acids, bases, surfactants, or trace hydrocarbon solvents; hydrocarbon solvents; or liquefied gas or supercritical fluids. The extraction usually occurs in a reactor that is designed to provide intimate contact between the extractant and the solid. Following this contact step, the extractant is treated for removal of the contaminants and then recycled for additional extraction steps. Generally, the efficiency of the extraction is based upon the ability of the process to overcome the three primary physical/chemical phenomena that hold the contaminants to the solid matrix: (1) entrapment, (2) adsorption, and (3) chemical bonding. Entrapment is a physical phenomena that occurs when the contaminants are embedded within the solid matrix. Adsorption, on the other hand, is a surface phenomena that involves the development of weak chemical bonds between the contaminant and active adsorption sites on the surface of the solid.

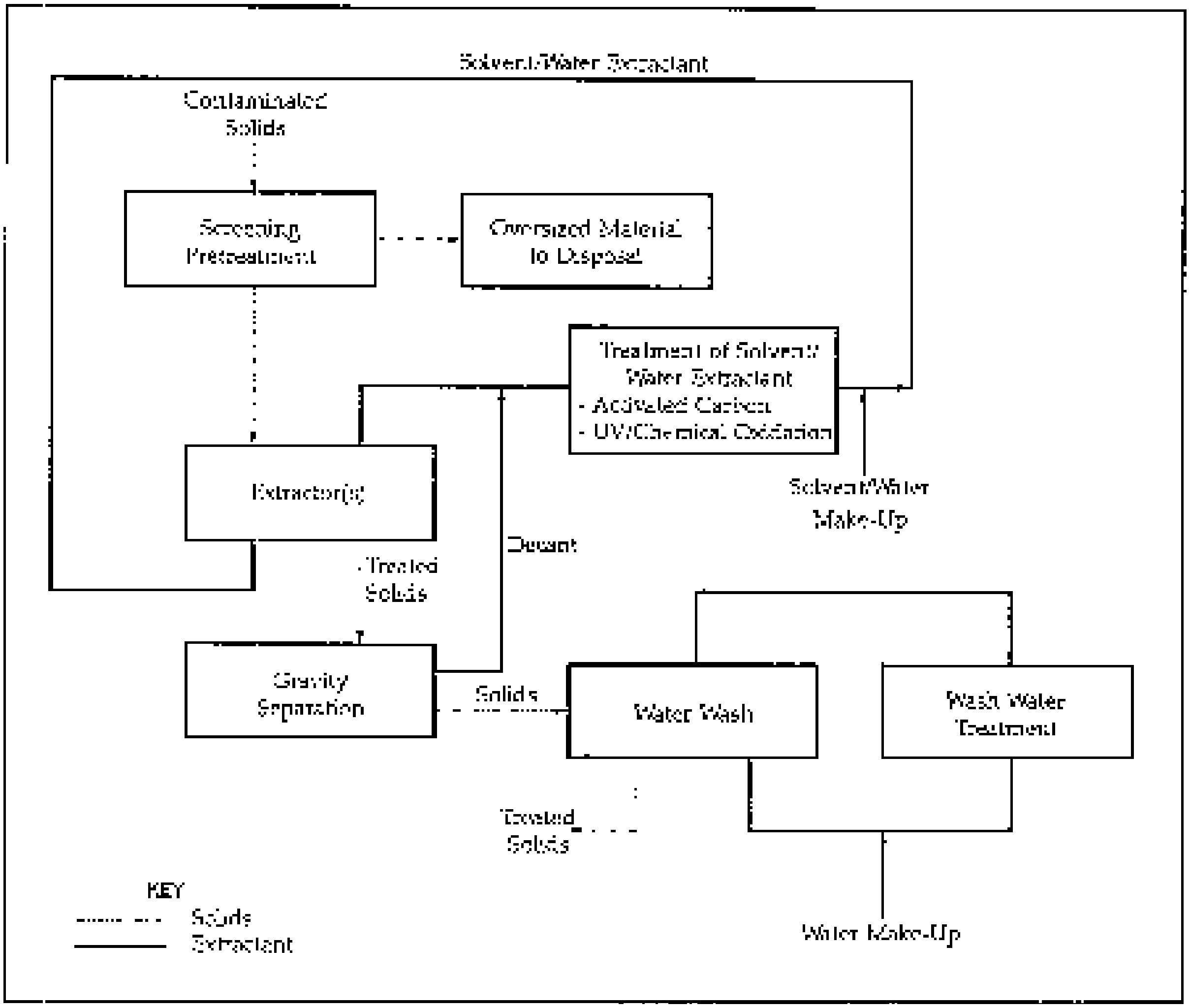


Figure A-14. Process Flowsheet for Aqueous/Solvent Extraction.

Stronger chemical bonds can also exist as a result of chemical reactions between the contaminant and the chemical components of the solid matrix. Entrapment can be overcome by disaggregating the solid with intense mixing or the addition of solvents or chemicals. This disaggregation exposes the contaminants to the extractant and improves the overall efficiency of contaminant removal. The weak chemical bonds of adsorption as well as the stronger chemical bonds from surface chemical reactions must be overcome by providing more favorable conditions in the extractant, i.e., a more thermodynamically stable state.

Figure A-14 provides a process flowsheet of an aqueous/solvent extraction treatment system. This process utilizes water enhanced with a miscible polar solvent (e.g., methanol/water mixture) as the extractant. The contaminated solid is appropriately sized and charged to a complete mix extractor, or multiple extractors in Series. The solids are contacted with a solvent/water extractant that flows countercurrent to the flow of solids. The flowrates of both the solid and the solvent/water extractant are determined by the desired level of treatment. These flowrates establish the volume of solvent/water solution required per mass of solid. Another critical design factor is the fraction of solvent in the water which, if increased, can decrease the volume of the extractant that is required to achieve the same level of treatment. Laboratory studies have also determined that two reactors in series are more efficient than a single reactor and therefore result in the use of less extractant per unit mass of solid. It is important that the proper residence time be provided in the extractor to ensure that the equilibrium partitioning of the contaminant between the extractant and solid has been achieved. The process that is shown in Figure A-14 can be operated on a continuous, batch or semi-continuous mode.

Following extraction, the extractant must be treated prior to reuse in the next extraction cycle. For example, specifically for organic contaminants, a methanol/water extractant can be treated using either activated carbon or UV/chemical oxidation (e.g., ozone, hydrogen peroxide, or a combination of these with UV light). These processes will remove the organic contaminants without reacting with the methanol.

From the extractor, the treated solids pass through a gravity separation step. Depending on the physical size classification of the treated solid, a separation process in addition to gravity settling may be needed. This may be the case when soil containing a high content of silt and clay is undergoing treatment. In this instance, a stable soil/water emulsion or "mud" may form which can only be separated by filtration or centrifugation. The filtrate is returned to the extraction process and the recovered solids will be subjected to a final water wash to remove any residual extractant prior to final disposition. The organic contaminants in this wash water may be sufficiently dilute to permit its direct discharge to a POTW or surface water. As an alternative, this wash water can be reused or subjected to treatment prior to disposition.

It is to be noted that the extraction system presented in Figure A-14 is not intended to represent an optimal process, but is only provided to illustrate all of the process elements that must be addressed for full-scale implementation of this treatment option. As such, there is much room for improvement to increase treatment efficiency and to reduce the cost of treatment. However, this optimization can only be done after conducting a lab-scale or pilot-scale test program.

PERFORMANCE:

Lab-scale testing results have demonstrated greater than 99 percent reduction of PAHs from coal-tar contaminated soil using a 100 percent methanol. Other studies have indicated that significant concentrations of either solvents or surfactants in water are required to achieve substantial reductions in contaminant concentrations. As such, additional lab-scale data are required to fully characterize the operating envelope for aqueous/solvent extraction such that the economics of this treatment option can be evaluated.

It should be noted that the investigative studies which have been conducted on liquid/solid bioslurry reactors is relevant to aqueous extraction since the first step in the liquid/solid bioslurry treatment of contaminated solids is the extraction of the contaminant from the solids. While it is understood that the presence of the nutrients and microorganisms may enhance the mass transfer of contaminants that occur, the data from these studies do provide a first-order assessment of the performance of aqueous extraction of organic-contaminated soils from MGP sites.

REFERENCES:

Ellis, W. O., J. R. Payne, and G. D. McNabb, "Treatment of Contaminated Soils with Aqueous Surfactants," EPA Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, 1985.

Villaume, J. F., P. C. Lowe, and D. F. Unites, "Recovery of Coal Gasification Wastes: An Innovative Approach," *Proceedings of the Third National Symposium on Aquifer Restoration and Groundwater Monitoring,* Columbus, OH, pp. 434-443, 1983.

Luthy, R. G., D. A. Dzombak, C. Peters, M. A. All, and S. B. Roy, *Solvent Extraction for Remediation of Coal Tar Sites,* [USGS/G-1913], U.S. Geological Survey, Reston, VA and Carnegie Mellon University, Dept. of Civil Engineering, September, 1992.

Luthy, R. G., D. A. Dzombak, C. Peters, M. A. All, and S. B. Roy, *In Situ Solvent Extraction for Remediation of Coal Tar Sites,* [Research Project 3072-2 Draft Final Report], Electric Power Research Institute, Palo Alto, CA, March, 1992.

BRICK MANUFACTURE

MEDIA:

Contaminated soil, sediment, and purifier box wastes.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, heavy metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Organic-contaminated soils have been processed in brick manufacturing facilities. Demonstration tests have been conducted using contaminated soils from MGP sites and permit modifications have been obtained for a facility in Ohio. Brick manufacturing facilities in the southeast have also applied for similar permit modifications.

DESCRIPTION:

The manufacture of bricks requires shale, clay, sawdust, and water (sawdust is added to create pores within the brick to improve the absorption .of mortar during construction). The process begins by mixing shale that has been crushed to a fine powder with clay. This mixture is combined with water and mixed into a plasticized mixture, which is then extruded and molded into green brick. The green bricks are placed in a drying room where air (100 to 600°F) is circulated. This reduces the moisture content of the bricks to approximately one percent. Drying time depends on the condition and moisture content of the brick but normally ranges from 24 to 48 hours.

The dried bricks are then preheated to approximately 1,000°F in the front end of a 500-foot tunnel kiln. The preheated brick is then fired at 1,500°F for approximately 12 hours (see Figure A-15). After a slow cooling process to avoid cracking and color change, the bricks are prepared for shipping. The total travel time in the kiln is approximately 2 to 5 days.

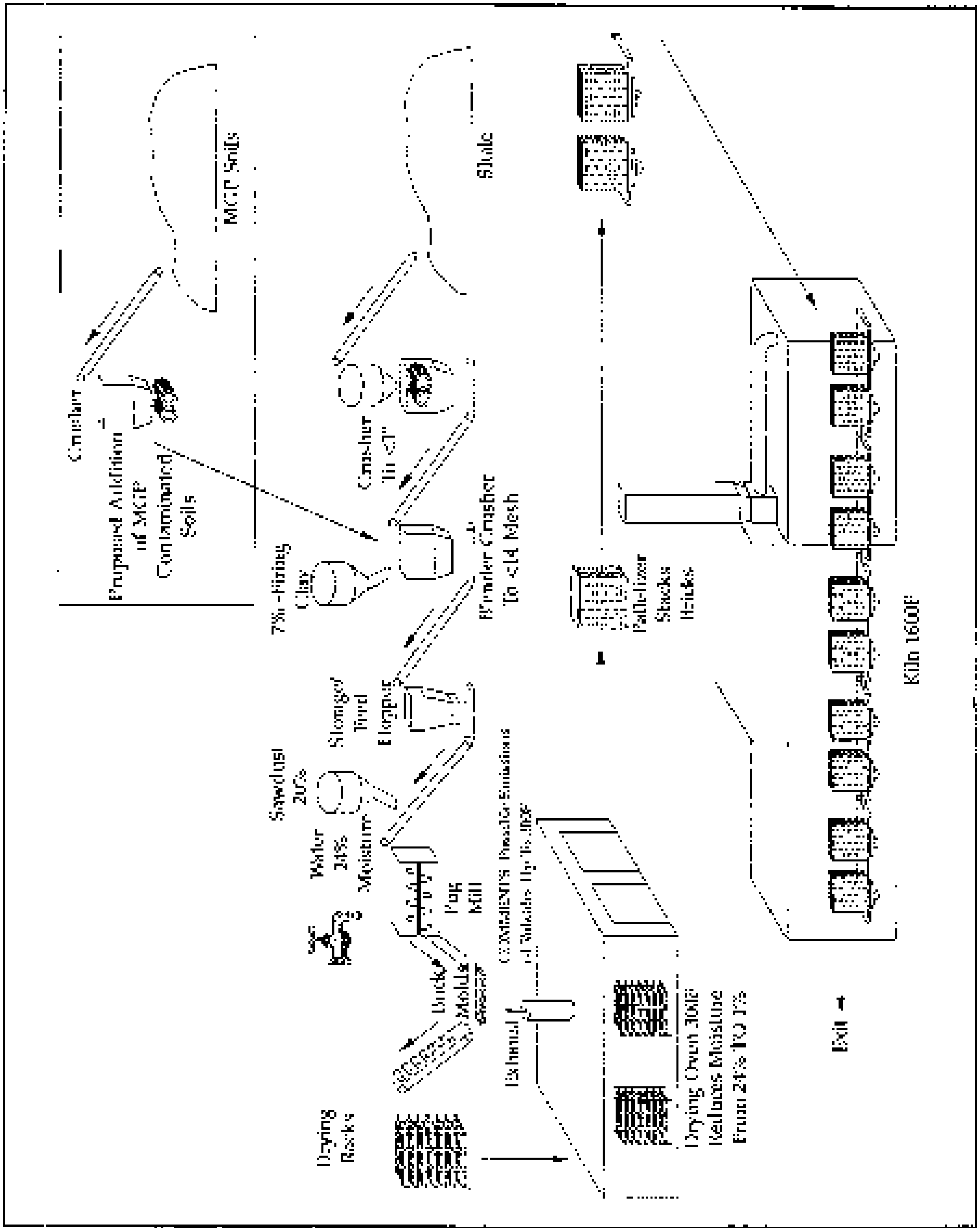


Figure A-15. **Process Flowsheet for Brick Manufacturing (with the Addition of Contaminated Soils).**

In theory, the brick-making process blends the contaminated solid with the clay and shale and it becomes part of the brick. The organic contaminants are presumably volatilized and destroyed as are some of the inorganic contaminants. The remainder of the inorganic contaminants and heavy metals are bound within the brick matrix. Contaminated solids typically require pre-processing, including crushing, screening, and blending prior to use in the manufacture of the bricks.

PERFORMANCE:

Brick manufacturing has been demonstrated for the recycling of contaminated soil from MGP sites. A demonstration test was conducted by Richland Moulded Brick in Ohio which incorporated approximately 20 percent by weight of organic-contaminated soil into the brick manufacturing process. As part of this test, the organic contaminant emissions from the firing kiln were monitored. The air monitoring test results met the requirements of the Ohio EPA and the facility was awarded a permit to process these contaminated residuals on a regular basis.

MGP site residuals appear to be compatible with the raw materials for brick, although additional preparation may be required to size contaminated wood chips, to crush larger soil particles, concrete, or brick and to remove other unsuitable debris, such as steel. Target contaminants may be emitted to the atmosphere from the kiln and drying 'oven; hence, these. potential emissions must be quantified with air monitoring as part of a demonstration test. It is possible that add-on emission control devices (e.g., afterburner) and/or process modifications (e.g., offgas recirculation) may be required to achieve the desired air emission levels. If required, the cost of using these materials in brick manufacturing may increase significantly.

REFERENCES:

Nash, James H., Seymour Rosenthal, George Wolf, and Marilyn Aver, *Potential Reuse of Petroleum-Contaminated Soil: A Directory of Permitted Recycling Facilities.*

"Building Material Survey: Bricks," Kirk-Othmer, *Encyclopedia of Chemical Technology, Volume IV*, Interscience Publishers, Division of John Wiley and Sons, Inc., New York, NY.

CEMENT MANUFACTURE

MEDIA:

Contaminated soil, sediment, purifier box wastes, and free-phase hydrocarbons.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, heavy metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Full-scale applications to contaminated solids and hazardous waste-derived fuels from the wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Contaminated soils from MGP sites have also been processed in commercial cement manufacturing facilities.

DESCRIPTION:

Two cement-making processes are currently in use, a "wet" process and a "dry" process. In the "wet" process, the raw materials are introduced in a slurry form. This process is more energy intensive than the "dry" process which introduces the raw materials as dry solids. For both processes, two options exist for the management of MGP site residuals. First, free-phase hydrocarbons with a high heating value can be used as a fuel substitute or supplement to heat the rotary kiln. The use of these hydrocarbons as a fuel substitute or supplement requires that it be used without any pretreatment and that it contains greater than 40 percent combustible organics and supplies greater than 50 percent of the required energy. Second, low heat content solids such as soils can be combined with the raw materials and can be incorporated into the cement product.

As shown in Figure A-16, cement kilns can use liquid hydrocarbons as alternative fuels by injecting them into the hot side of the kiln. Also, solids can be ground and used in place of or mixed with coal and used as a primary fuel. These fuels can be sent directly to the owners of the kilns or, more likely, to fuel blenders which act as brokers for specific kilns. Low heat content solids are typically mixed with the raw feed to cement kilns. The "wet" process is also capable of using contaminated water as a water substitute or supplement. Once the contaminated solid is incorporated into the raw materials, the mixture enters into the elevated cold end of the kill and flows toward the high temperature zone. The elevated end of the kiln is considered the preheating or drying zone where moisture is removed from the raw materials at temperatures approaching 1,500°F.

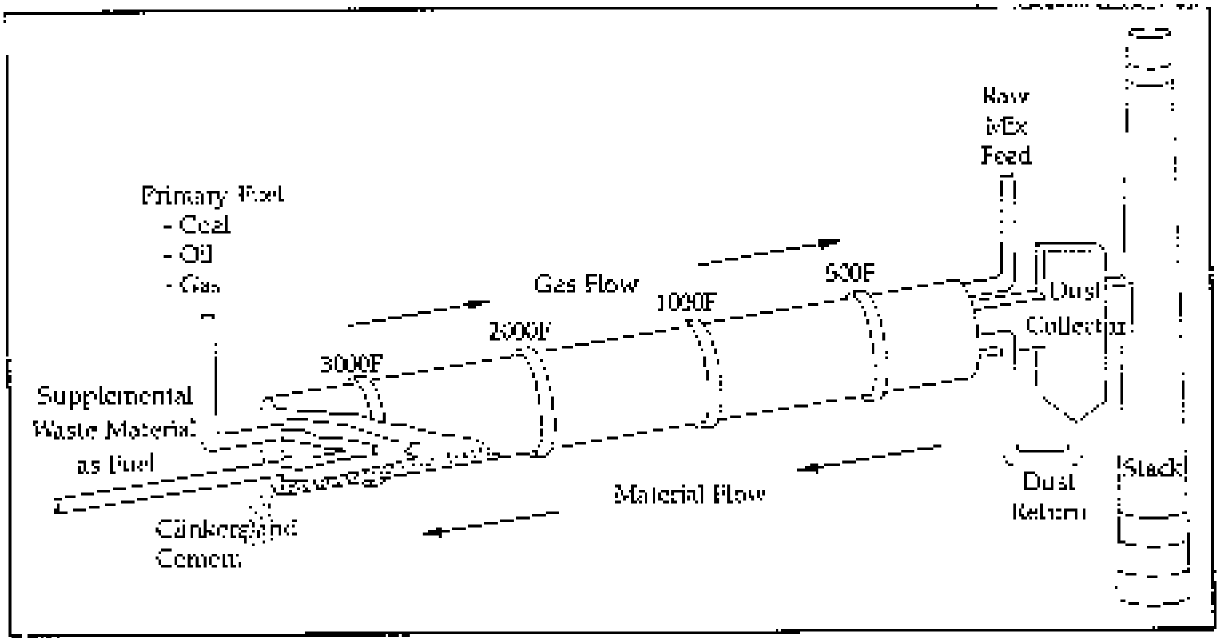


Figure A-16. Process Flowsheet for a Cement Kiln.

The raw materials gravity flow through the preheating zone and into the calcining zone where carbon dioxide is driven' from the limestone at temperatures reaching 2,200°F. Finally, the raw materials flow into the sintering zone. In this zone, the raw materials are heated to 3,500°F and clinkers are formed. The clinker is cooled, mixed with gypsum, and ground to form the cement product.

As shown in Figure A-16, gases in the kill flow countercurrent to the raw material. After the gases reach the elevated end of the kiln, they pass through a dust collector. The gases are then discharged to the atmosphere through a stack.

Cement kilns are limited to recycling wastes which meet certain specifications and/or limitations. These specifications and limitations are usually specified as part of the air quality permit for the kiln which is issued by the state. This permit would have to be amended to recycle contaminated materials from MGP sites into the process. A listing of waste specifications/requirements for northeastern cement kilns is presented in the Table A-2; however, these specifications can change at any time in response to changing regulations as well as changes in the operation of the cement kiln.

PERFORMANCE:

Cement kilns have been used in Europe for the effective and safe disposal of chemical wastes and hazardous substances. The EPA has conducted several test burns on cement kilns in the United States. The conclusions from these test burns has been that cement kills furnish an effective set of conditions for contaminant destruction. Also, virtually all metals introduced into a kiln are stabilized as part of the clinker or kill dust. Extensive studies have shown that metals bound in clinker or kiln dust will not leach.

More specific to MGP site residuals, cement kilns have successfully incorporated soils contaminated with VOCs and PAHs into the cement product. Contaminated soils from MGP sites have been processed at both the Cemtech/Heartland Cement Company facility in Independent, Kansas, (43 tons) and at the Giant Resource and Recovery, Inc. (GRR) facility in Harleyville, South Carolina (3,600 tons). The Cemtech/Heartland cement facility crushed and mixed the non-hazardous materials with traditional raw materials for cement manufacture. The mixture was then processed into clinkers over a period of 3 to 5 hours at 3,500°F. At the GRR facility, the contaminated soil was initially fed into a rotary kiln where it was subjected to temperatures of 1,800°F for 45 minutes. The exhaust gases from this kiln were fed into the center of the cement kiln where complete oxidation at 3,500°F took place. The treated soil from the rotary kiln was combined with traditional raw materials and processed in the cement kiln to form clinkers.

REFERENCES:

Gas Research Institute, *Fuel-Use Options for the Management of MGP Site Wastes*, GRI-89/0023, Chicago, IL, February, 1989.

"Cement Kilns Can Treat Wide Variety of Hazardous Wastes," *The Hazardous Waste Consultant*, July/August, 1991.

Table A-2. Waste Specifications for Recycling in Cement Kilns.

Cement Co.	Essroc		Independent	Keystone	Lafarge			Medusa
Broker	Cadence		Riedel	Industrial Oil	Systech			NA
Waste Type	Pumpable Liquid	Solid Wsate	Hazardous Waste	Pumpable Liquid	Pumpable Liquid			Bulk Liquid
Waste Category	K Blend	S Blend	NA	NA	Category 1	Category 2	Category 3	NA
Heating Value, BTU/lb	> 10,000	> 6,000	> 5,000	> 8,000	> 10,000	> 8,500	> 6,000(3)	> 10,000
Water Content, %	NA	NA	5 / 20(2)	20	1	2	3	20
Chlorine Content, %	NA	NA	4	NA	3	5	10	4
Organohalogen, %	5	5	NA	NA	NA	NA	NA	NA
Ash, %	NA	NA	30	NA	7	10	15	NA
Pesticides, mg/kg	50	50	NA	NA	NA	NA	NA	NA
PCBs, mg/kg	50	50	30	NA	NA	NA	NA	10
pH, s.u.	2 - 12.5	2 - 12.5	NA	NA	4 - 11	4 - 11	4 - 11	NA
Viscosity, cp	NA	NA	3,000(2)	NA	100	200	330(4)	NA
Sulfur, %	3	3	3	NA	NA	NA	NA	NA
Nitrogen, %	NA	NA	1	NA	NA	NA	NA	NA
Flashpoint, °F	NA	NA	> 70	NA	NA	NA	NA	NA
TSS, %	30	NA	NA	NA	NA	NA	NA	NA
Metals, mg/kg								
Antimony	100	100	1,000	NA	NA	NA	NA	NA
Arsenic	200	200	50	NA	NA	NA	NA	NA
Barium	2,000	2,000	4,000	NA	4,000	6,000	10,000	NA
Berillium	10	5	0.5	NA	NA	NA	NA	NA
Cadmium	300	30	150	NA	NA	NA	NA	NA
Chromium	10,000	1,000	2,000	NA	NA	NA	NA	NA
Cobalt	NA	NA	4,000	NA	NA	NA	NA	NA
Copper	NA	NA	4,000	NA	NA	NA	NA	NA
Lead	10,000	1,000	2,000	NA	4,000	6,000	10,000	NA
Magnesium	NA	NA	10,000	NA	NA	NA	NA	NA
Mercury	25	10	2	NA	NA	NA	NA	NA
Nickel	NA	NA	2,000	NA	NA	NA	NA	NA
Osmium	NA	NA	1,000	NA	NA	NA	NA	NA
Selenium	NA	NA	100	NA	NA	NA	NA	NA
Silver	4,750	475	250	NA	NA	NA	NA	NA
Thalium	750	75	1,000	NA	NA	NA	NA	NA
Titanium	NA	NA	10,000	NA	NA	NA	NA	NA
Vanadium	NA	NA	2,000	NA	NA	NA	NA	NA
Zinc	NA	NA	4,000	NA	4,000	6,000	10,000	NA

Note: [1] All values are maximum values unless otherwise noted. [2] Values are for liquid wastes.
[3] Material with a heating value less than 8,500 BTU/lb must have less than 5% chlorine.
[4] Material must be pumpable using a positive displacement pump.
NA = Compound not analyzed for acceptance.

CHEMICAL OXIDATION

(See CHEMICAL OXIDATION: *EX SITU* TREATMENT OF CONTAMINATED WATER)

CO-BURNING IN A UTILITY BOILER

MEDIA:

Contaminated soil, sediment, purifier box wastes, and free-phase hydrocarbon.

TARGET CONTAMINANTS:

VOCs, PAHs, phonelics, heavy metals and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Utilities have been co-burning contaminated materials at their power generating stations over the past several years. Materials which have been processed include such items as tires, wastes oils, waste solvents, and soils contaminated with a range of organic chemicals. More recently, several utilities have co-burned contaminated soils from MGP sites at these facilities. In all but two instances, the burns were demonstration tests that were. conducted to determine technical feasibility and to obtain regulatory approval for future management of similar soils. The other two cases (Minnesota and New York) represented the co-burning of contaminated soils from the remediation of two MGP sites.

DESCRIPTION:

Free-phase hydrocarbons from MGP sites can have heat contents in the range of 15,000 to 20,000 BTU/lb which is only slightly less than that of No. 6 fuel oil. Purifier box wastes and heavily contaminated soils (i.e., free phase hydrocarbon concentrations of 10% to 30%) can have heat contents in the range of 3000 to 5000 BTU/lb. As such, the co-burning of these materials in utility boilers has become a topic of investigation. More recently, these investigations have been extended to include lightly to moderately contaminated soils that have little or no heating value. The argument for the processing of these materials is that the residuals are managed at all times under the control of the utility, the contaminants are destroyed, and the cost of this management option may be significantly less that most other treatment alternatives. Since the majority of soil consist of inert geologic materials such as sand or clay, the primary potential environmental impact of their treatment in the boilers is on the management of the ash. Table A-3 lists the critical soil parameters of interest when considering co-burning in a utility boiler. It can be seen from this table, that in addition to some of the conventional environmental parameters, there is a heavy emphasis on the composition of the ash as well as the overall physical characteristics of the soil.

Table A-3
PARAMETERS OF INTEREST FOR FEASIBILITY EVALUATION OF CO-BURNING IN UTILITY BOILERS

Physical Characteristics of Soil	Ash Chemical Characteristics
Particle Size Distribution	Fe
Density	FeO
Grindability Index	Fe_2O_3
Gross Chemical Characteristics	CaO
Moisture	MgO
Volatile Matter	Na_2O
Ash	K_2O
Unknown Matter	SiO_2
Carbon	Al_2O_3
Hydrogen	TiO_2
Sulfur	MnO_2
Nitrogen	SO_3
Oxygen	PO_5

Most power generating facilities generate steam using cyclone, pulverized coal, or stoker boilers. MGP site residuals are co-burned in these units by blending them with the feed coal at coal to residual weight ratios ranging from 100:1 to 20:1. The residuals must be processed to less than 3/4 inch prior to entering the coal processing equipment for both the cyclone and pulverized coal boilers; much less stringent size reduction is needed for the stoker boiler. Separate storage and handling facilities may be required for the residuals at the power generating facility to provide the ability to control particulate emissions and to isolate and manage the surface runoff from these materials. Furthermore, the quantities of fly ash and bottom ash will increase although it is anticipated that no significant changes in any equipment downstream of the boiler will be required. However, this will have to be evaluated on a case-by-case basis for each application.

The feasibility of this management option for MGP site residuals must be evaluated individually by each utility. The purpose of these feasibility studies is to determine if the co-burning of the MGP site residuals will interfere with the ability of the power generating units to reliably produce electricity at their rated output. Technical investigations must be initiated to address solids receiving, storage, and handling; coal handling and feed systems; impact of residuals on combustion performance and stack gas emissions; effects of residuals on furnace corrosion; effects of residuals on ash handling and disposal systems; and surface water runoff storage and treatment. Other considerations include worker health and safety, local public acceptance, and overall logistical considerations associated with the location of the sites, the onsite processing of the residuals, and the transport of the residuals from the MGP sites to the power generating facilities. It is likely that the final step in the feasibility study analysis will be a demonstration test burn at the power generating facility. The test burn will establish if the residuals can be co-burned in the facility, the acceptable feed rate, and their environmental and operational impact on the facility.

PERFORMANCE:

Several demonstration test burns have been conducted at utility boilers in the midwest and northeast. Although the details of these tests have not been thoroughly reviewed, it is understood that no significant problems were identified during any of them. In most cases, the test burns established the maximum feed rate of the residuals which could be tolerated by the power generating facility without causing any operational or environmental difficulties. In the two cases where substantial quantities of contaminated soil were co-burned as part of a site remediation, one required a temporary modification of the facility air permit whereas the other was conducted as part of a Research Demonstration and Development Permit. In the latter case, a state Environmental Impact Statement was also completed and published for public review and comment. The EIS has been filed because the utility intends to continue to co-burn MGP site residuals as part of an environmental service business which will serve the utility industry-at-large.

REFERENCES:

No references.

COLD-MIX ASPHALT

MEDIA:

Contaminated soil and sediment.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, heavy metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Soils contaminated with petroleum and/or petroleum-derived products (e.g., diesel and gasoline) have been used to produce cold-mix asphalt. An onsite demonstration test has been conducted in the Northeast using contaminated soils from an MGP site.

DESCRIPTION:

Contaminated soil or sediment is pre-processed by crushing and/or screening to produce a physically uniform material that is free of debris. After preprocessing, the soil is transferred into a feed hopper where it is conveyed to the mixing chamber (typically a pugmill) by a belt feeder. As the soil passes through the mixing chamber, a liquid asphalt emulsion is added at a predetermined rate. The mixture of asphalt and soil exits the mixing chamber and is stockpiled for 72 hours to allow the mixture to cure. The mixture may require cover to prevent the infiltration of precipitation. Should this be the case, 'the curing duration would likely be extended.

Cold-mix asphalt is typically used for paving secondary roads. Suitability of the product is determined based on the following specifications:

- **Stability** — resistance to deformation;
- **Durability** — resistance to weathering, crushing, and degradation;
- **Flexibility** — ability to conform to long-term variations in the base due to settling and the ability to bend repeatedly without fracture;
- **Skid Resistance** — the ability to allow reasonable traction in all weather conditions;
- **Permeability** — low permeability to prevent water absorption; and
- **Workability** — the ability to achieve a smooth finish when placed and compacted in the road.

When incorporating contaminated soil into the mixture, grain size analysis and moisture content tests are required to determine the amount of aggregate for ideal gradation and the type of liquid asphalt for product stability.

PERFORMANCE:

The cold-mix asphalt process can be conducted onsite and is not subjected to significant environmental permitting. This is attributed to the fact that the process mixing occurs at ambient temperatures and the majority of the organic contaminants have boiling points significantly greater than ambient conditions. Exceptions to this would be contaminants such as benzene or naphthalene.

Cold-mix asphalt produced from contaminated soils at MGP sites was subjected to aqueous leach tests and aquatic bioassay testing using minnows as the test organism. Zero mortality rates were recorded for all samples and leachate concentrations were less than detection limits for PAHs (except naphthalene) and less than the regulatory limits for all heavy metals. However, water quality criteria for benzene, toluene, and naphthalene were exceeded in the leachate for selected samples. Additional testing of these products are planned including a laboratory-based column extraction test and a field demonstration test to investigate product leaching, strength, and stability.

REFERENCES:

Neeley, William E., "Contaminated Soil Recycled in Road Mix," *Soils,* November-December, 1990.

COMPOSTING

MEDIA:

Contaminated soil and sediment.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, conventional pollutants such as BOD, COD, and TOC.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated soil from the wood treating, coal-tar distillation, coke manufacturing, and petroleum refining and storage industries. Limited lab-scale applications to contaminated soil from MGP sites.

DESCRIPTION:

Composting is an approach to biological treatment that has historically been used to treat wastes with high concentrations of biodegradable organic solids (e.g., dead vegetation). From an industrial perspective, composting is an emerging technology for the treatment of organic-contaminated soil and sediment. This type of treatment consists of piling the contaminated material, sometimes mixed with a bulking agent, at heights of three to six feet. The addition of bulking agents facilitates mixing and enhances oxygen transfer. Aeration is provided by either forcing air through a contained system, such as in "Soil Heap Composting," or by mechanically turning over the soil which also serves to mix the material, such as in "Windrow Composting." Both of these systems are illustrated in Figure A-17.

Composting systems are amenable to moisture, pH, and nutrient control by simple irrigation techniques, and to volatile emission control using system enclosures or vacuum systems for air movement. When temperature is critical to treatment efficiency, the compost pile can be amended with other sources of organic matter to increase biological activity, and hence, the temperature of the system; or the composting piles can be covered or enclosed for better process and temperature control.

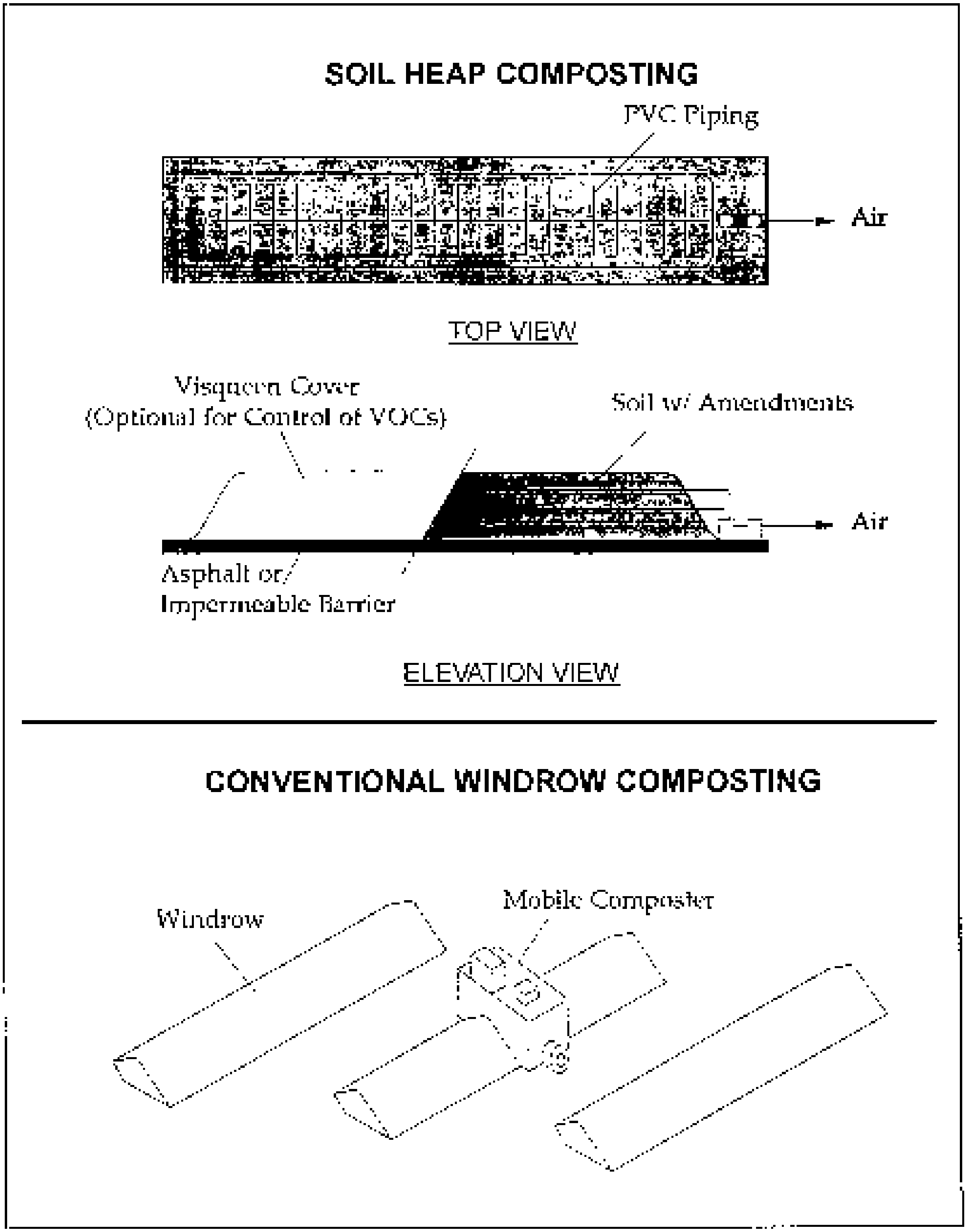


Figure A-17. Process Flowsheet for Typical Composting Processes.

Treatment of contaminants in compost systems, like all other biodegradation processes, is limited by the ability to desorb them from the contaminated solid. However, at this point, the contaminated material no longer represents a source of contamination to groundwater and is said to be biostabilized.

PERFORMANCE:

The specific application of this technology to MGP site residuals is greatly influenced by the specific chemical contaminants and the specific soil characteristics. However, some preliminary studies show promising results as summarized below:

- greater than 62 and 25 percent degradation of pyrene and chrysene, respectively, in a short-term laboratory study;
- greater than 90 percent degradation of coal-tars achieved during an MGP facility remedial effort; and
- reduction of total petroleum hydrocarbons to less than 100 ppm in less than 60 days

REFERENCES:

Hunter, J. V., and M. S. Finstein, "Microbial Decomposition of Hazardous Industrial Compounds Through Composting," Interim Project Report. Rutgers University, 1986.

Savage, G. M., et al., "Disposing of Organic Wastes by Composting," Biocycle, January/February, 1985.

HOT-MIX ASPHALT

MEDIA:

Contaminated soil, sediment, and free-phase hydrocarbon.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, heavy metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Contaminated soils associated with leaking underground storage tanks containing petroleum or petroleum-derived hydrocarbons have been processed in hot-mix asphalt plants. More recently, these facilities have begun to modify their permits to accept soils contaminated with free-phase hydrocarbons from MGP sites.

DESCRIPTION:

Hot-mix asphalt plants typically consist of a direct-fired rotary kiln with a multi-hopper soil/aggregate feed system as shown in Figure A-18. Soil and aggregate are metered into the rotary kiln via belt feeders. The relative quantities of soil and aggregate used are predetermined by the soil grain size analysis and the product specifications of the asphalt product. For most applications, the aggregate to soil ratio is approximately 5 to 1. Rotary kilns used for the production of asphalt can be constructed with the burner at either the elevated end or the lowered end of the kiln.

The soil/aggregate mixture is heated to approximately 500°F in the kiln. At this temperature, organic contaminants are volatilized from the soils. Inorganics, meanwhile, remain in the soil and report to the final product. Liquid asphalt is injected into the center of the kiln where it is mixed with the soil and aggregate to form bituminous concrete which is more commonly called "asphalt". The asphalt is discharged from the kiln and transported to a storage area or over-head silo until sold for pavement. The kilns are equipped with air pollution control systems (e.g., wet scrubber, baghouse, cyclone) to remove particulate from the offgas. The accumulated particulate can be fed into the kiln with the aggregate and soil or can be stockpiled and used as a sub-base for pavement. The fate of the volatilized organic contaminants is dependent upon the burner configuration of the kiln. If the burner is at the lowered end of the kiln, these contaminants have the potential to escape from the kill in the offgas.

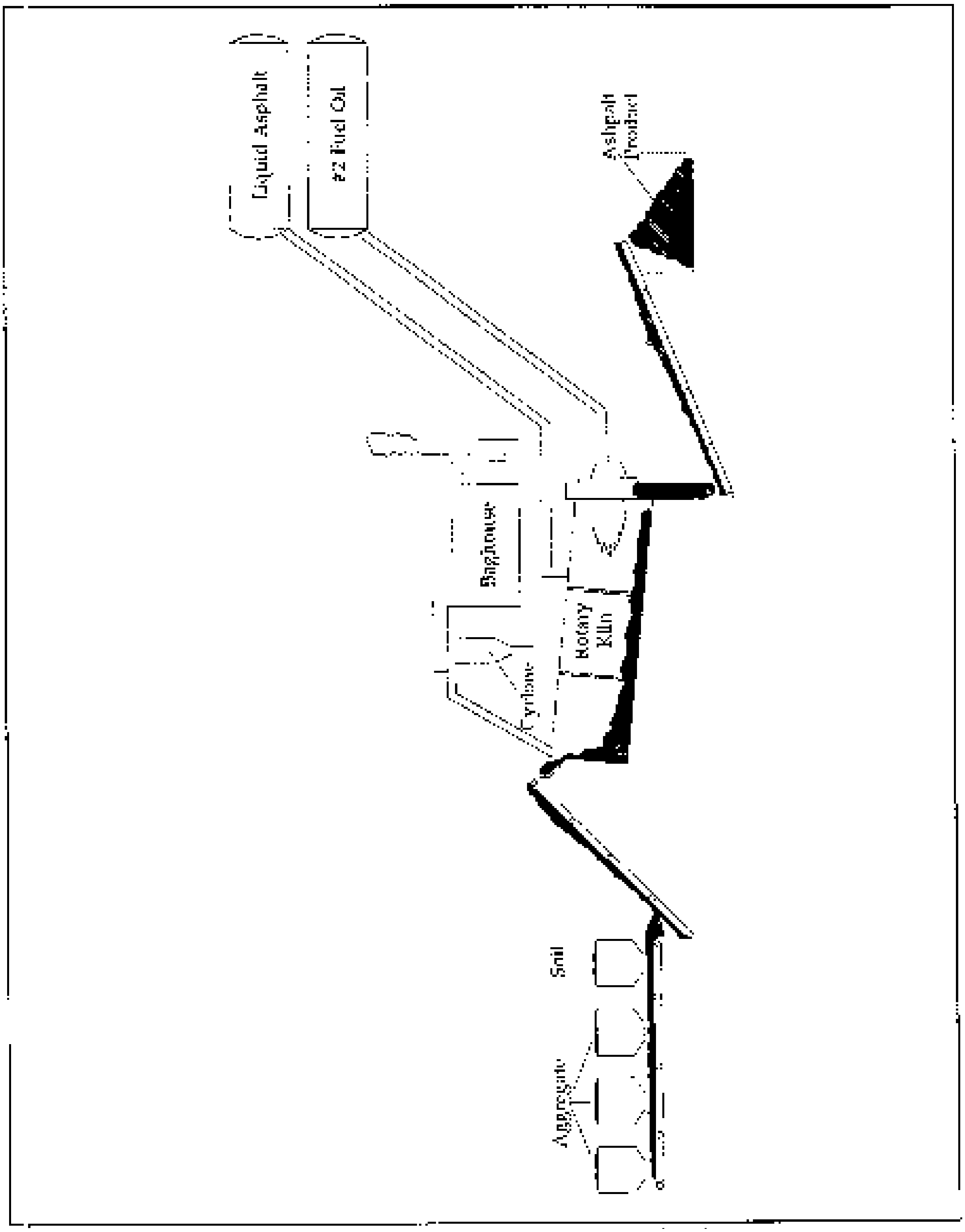


Figure A-18. Process Flowsheet for Hot-Mix Asphalt Production.

However, if the burner is at the elevated end of the kiln, the volatilized organic contaminants will pass through the hot end of the kill before exiting in the offgas. This flow pattern will likely result in the complete destruction of the organic contaminants and the reduction of organic contaminant emissions in the kiln offgas.

Contaminated soil and sediment with a high clay content can be processed through the kiln without the addition of aggregate and asphalt to produce a treated material that is suitable as a sub-base for many asphalt applications.

Free-phase hydrocarbons with a high heat content can be used as a fuel supplement and burned in the rotary kiln. The material must be pumpable and have a low solids content so that it does not foul the burner.

The future development of this management option for MGP site residuals will be on a regional basis. It will require the identification of the facility, the modification of the facility permits', and, in some cases, modifications to the facility equipment and operations. The utility will most likely have to lead the facility operator through this process with the enticement of future revenues as an incentive to make the necessary permit and facility modifications.

PERFORMANCE:

Several utilities have had contaminated soils from MGP sites processed into hot-mix asphalt. One northeast utility sent 12,000 tons of contaminated soil to a facility in Virginia which thermally desorbed the soil prior to selling it to a hot-mix asphalt production facility as clean aggregate. In addition, a hot-mix asphalt production facility in Georgia has processed 25,000 to 30,000 tons. of organic-contaminated soils from MGP sites that contained 300 to 40,000 mg/Kg of total petroleum hydrocarbons and a facility in Wisconsin conducted a test to produce 50 tons of hot-mix asphalt. The asphalt product in Wisconsin was used as pavement at an operating power generation facility.

REFERENCES:

Neeley, William E., "Paving Firm 'Burns Dirt' for Hot-Mix Asphalt Use," *Soils,* January-February, 1991.

INCINERATION

MEDIA:

Contaminated soil, sediment, purifier box wastes, and free-phase hydrocarbon.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, cyanide, sulfur, and selected metals.

RELEVANT INDUSTRIAL EXPERIENCE:

Full-scale incineration has been performed on a wide variety of industrial liquid and solid wastes. The majority of the experience is with fixed-based offsite facilities although some use of transportable and/or mobile treatment units has also occurred. 'Only limited incineration of contaminated solids from MGP sites, either on site or offsite, has been documented to date.

DESCRIPTION:

Incineration refers to the high temperature oxidation of residuals. The basic incinerator components normally include a primary and secondary combustion chamber followed by an air pollution control system. The residuals are fed to the primary chamber which typically operates at 1000°F to 2000°F where the contaminants are volatilized into the gas phase and either pyrolized (in starved air environments) or oxidized (in the presence of air) to simple combustion products such as CO_2, H_20, HCl, and SO_2. Nitrogen containing compounds (i.e., NO_x) may also be formed. Liquid wastes can be incinerated completely within a single high temperature combustion chamber. For most solids, a higher temperature secondary combustion chamber (SCC) which typically operates at between 1800°F and 2200°F is usually required after the primary chamber to assure complete destruction of all volatilized contaminants that might carry over from the primary combustion chamber. Table A-4 summarizes some of the more common incineration technologies. A complete incineration system includes these technologies as well as the following systems: a feed system, an ash handling system, a heat recovery system, and air pollution control system. A general process flowsheet that includes these basic components for a conventional rotary kiln incineration system is shown in Figure A-19.

Table A-4

SUMMARY OF COMMONLY USED INCINERATION TECHNOLOGIES

Type	Process Principles	Application	Combustion Temperature	Residence Time
Rotary Killn	Waste is burned in a rotating, refractory cylinder	Any combustible solid, liquid or gas	1500-3000°F	Seconds for gases to hours for liquids and solids
Single Chamber/Liquid Injection	Wastes are atomized with high pressure air or steam and burned in suspension	Liquids and slurries which can be pumped	1300-3000°F	0.1 to 1 second
Multiple Hearth	Wastes descend through several grates to be burned in increasingly hotter combustion zones	Sludges and granulated solid wastes	1400-1800°F	Up to several hours
Fluidized Bed Incineration	Waste is injected into an agitated bed of heated inert particles. Heat is efficiently transferred to the wastes during combustion.	Organic liquids, gases and granular or well processed solids	1400-1600°F	Seconds for gases and liquids, minutes for solids
Infrared Incinerator	Wastes are conveyed on a moving "belt" through the furnace with infrared energy as the heat Source	Gases and solids	500-1850°F	Seconds for gases to hours for solids

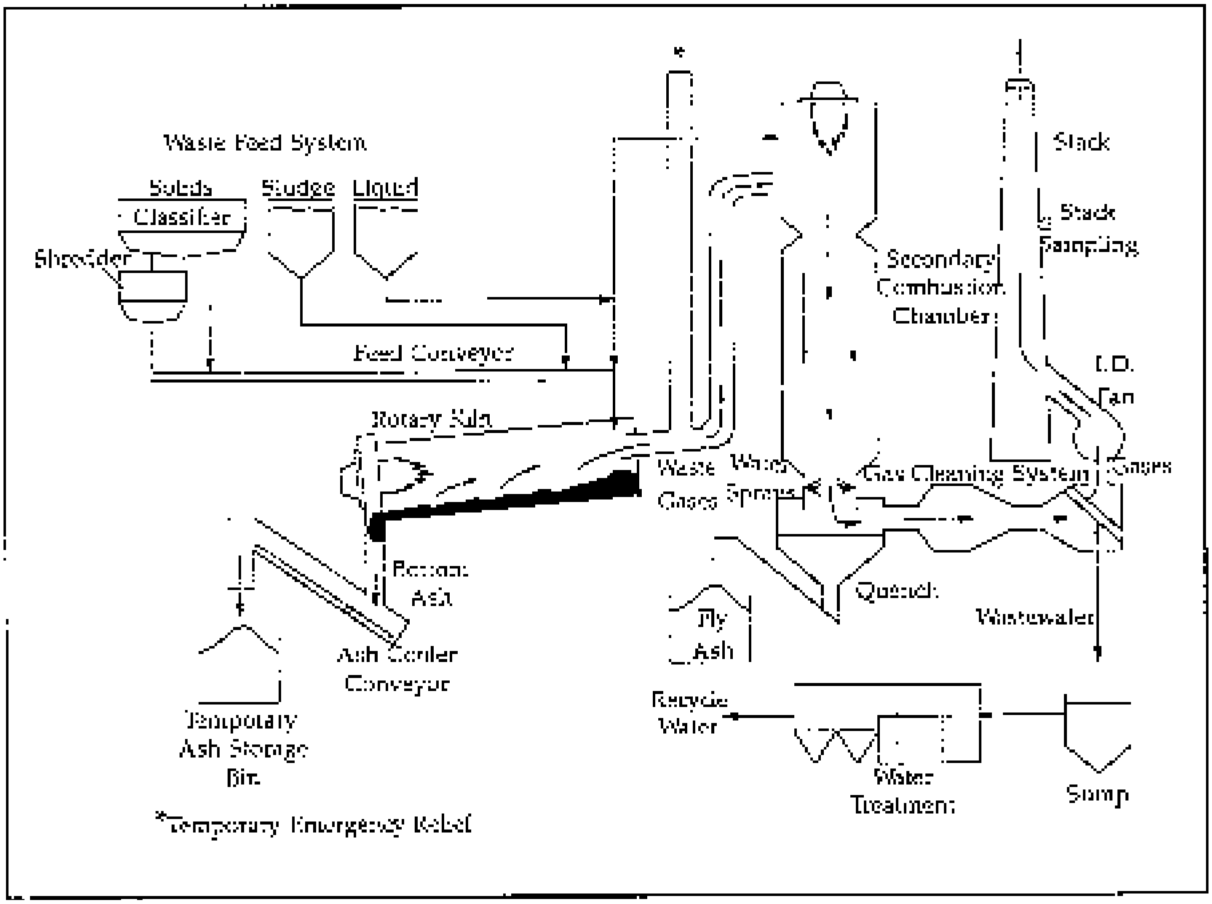


Figure A-19. Process Flowsheet for Countercurrent Rotary Kiln Incineration System.

Incineration can be achieved using both mobile transportable and fixed-base units. The fixed-base systems are located at offsite facilities and typically consist of large, rotary kilns ranging in size from 80 to 100 MM BTU/Hr and with solid capacities of 20 tons per hour or greater. The mobile/transportable units consist primarily of:

- rotary kilns
  - Small: < 20MM BTU/Hr, 1-2 Tons/Hr;
  - Medium: 20 to 40 MM Btu/Hr, 4-7 Tons/Hr; and
  - Large: > 40 MM BTU/Hr, > 10 Tons/Hr.
- infrared conveyor furnaces: 5-7 Tons/hr; and
- fluidized bed combustors: 4 Tons/hr.

Both the fixed and mobile/transportable systems are currently available for full-scale application to MGP site soils. As of 1989, 13 companies within the United States offered these services and had full-scale remediation experience on source materials and contaminated media [Cudahy, 1989]. A list of the commercial incinerators that were permitted by the U.S.. EPA as of that time are listed in Table A-5.

Table A-5

LIST OF COMMERCIAL INCINERATORS OPERATIONAL IN 1989

Facility Name	City, State	EPA ID#
Environmental Systems Co.	El Dorado, Arkansas	ARD069748192
SCA Chemical Services, Inc.	Chicago, Illinois	ILD000672121
Chemical Waste Management	Sauget, Illinois	ILD098642424
Olin Corp. Chemicals Group	Brandenburg, Kentucky	KYD006396246
LWD, Inc.	Calvert City, Kentucky	KYD088438817
Stauffer Chemical Co., Inc	Baton Rouge, Louisiana	LAD008161234
Rollins Environmental Services	Baton Rouge, Louisiana	LAD010395127
Rollins Environmental Services	Bridgeport, New Jersey	NJD053288239
Ross Incineration Services, Inc.	Grafton, Ohio	OHD048415665
Alchem-Tron, Inc.	Cleveland, Ohio	OHD980569438
Thermal Kem, Inc.	Rockhill, South Carolina	SCD044442333
GSX Thermal Oxidation Corp.	Roebuck, South Carolina	SCD984167616
Stauffer Chemical Co.	Houston, Texas	TXD008099079
Rollins Environmental Services.	Deer Park, Texas	TXD055141678

For the most part, offsite incineration is mainly suited for the low volume residuals that are present at an MGP site such as pumpable or non-pumpable free-phase hydrocarbons or purifier box wastes. This limitation is driven primarily by costs which are attributed to shipping and packaging requirements, distance to the facility, and the cost of treatment. The type of waste that a commercial incinerator can handle depends upon the type of incineration equipment, the requirements of the facility air permits, the hazardous waste classification of the material, and the nature of the contaminants of concern. The combustion of most of the MGP site residuals in these units should not be a problem although it is likely that trace metal, cyanide, and sulfur content of these materials will be closely scrutinized. This may result in the imposition of surcharges or possible rejection of the purifier box wastes since they have been documented to contain relatively high concentrations of the inorganic and heavy metal contaminants. With regards to heavy metals, arsenic, lead, and mercury may be the most restrictive due to their high relative volatility at incineration temperatures.

The advantage of incineration is that it can reduce the concentrations of all organic contaminants to very low levels in the solid matrices. Furthermore, it destroys the contaminants, converting them to carbon dioxide and water. This feature makes it a very attractive treatment technology for solid matrices that contain organic contaminants with a wide spectrum of chemical and physical properties. However, the presence of selected inorganic compounds, such as sulfur and nitrogen, and selected heavy metals can yield emissions in the incinerator offgas or leachates from the incinerator ash that are not acceptable to the regulatory agencies or the public. While these emissions and discharges can be adequately controlled, their presence can make the permitting process for onsite treatment units prohibitive, both in terms of time and money. This is especially true for MGP sites that are located in urban or residential settings. As such, it is often more expedient to utilize offsite incineration facilities which are fully permitted than to seek to permit an onsite unit. The penalty associated with this choice is the cost of transportation and the potentially high processing fees at the facility.

PERFORMANCE:

Treatment efficiency for solids, as measured by Destruction Removal Efficiency (DRE), has been reported as >99.99 percent for a variety of organic contaminants including VOCs and PAHs. Treatment efficiencies for inorganic contaminants such as cyanide is also very high although there are less data reported for this constituent. As for metals, the percentage reduction is dependent upon the chemical and physical properties of the individual compounds.

REFERENCES:

Gas Research Institute, Management of Manufactured Gas Plant Sites - Volume IV Site Restoration, Chicago, IL, GRI-87/0260.4, October, 1987.

Cudahy, J. J. and Anthony R. Eicher, "Thermal Remediation Industry: Markets, Technologies, and Companies," *Pollution Engineering,* pgs. 76-80, November, 1989.

LIQUID/SOLID BIOSLURRY

MEDIA:

Contaminated soil and sediment.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, ammonia, free/weak-acid dissociable cyanide, and conventional pollutants such as BOD, TOC, and COD.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated solids from wood treating and a petroleum refining industries. Extensive lab-scale applications have been applied to contaminated soil from MGP sites and a full-scale demonstration test is planned for 1994.

DESCRIPTION:

The liquid/solid bioslurry is a modified version of the activated sludge process that is used for the treatment of soil. An aqueous slurry, created by combining contaminated solids with water, is fed to a bioreactor and aerated. Aeration supplies oxygen to promote the aerobic microbial activity that is necessary to degrade the organic contaminants. Unlike prepared-bed land treatment and composting, liquid/solid bioslurry reactors maximize mass transfer rates. .by using intense aeration and mixing. The following five generic elements are common to most liquid/solid bioslurry reactor systems:

1. pretreatment of solids (if necessary);
2. creation of a liquid/solids slurry with mechanical agitation;
3. aeration and addition of nutrients and microorganisms;
4. dewatering of liquids/solids slurry; and
5. post-treatment (if necessary) of soil and water followed by ultimate disposal.

Pretreatment, post-treatment and ultimate disposal methods for the solids and water utilize standard techniques. The design of the liquid/solid bioslurry reactor is vendor-specific and includes a variety of hardware configurations. Figure A-20 provides a simplified process flowsheet for a liquid/solid bioslurry treatment system. In this figure, three reactors are operated in series although they could be operated in parallel. Furthermore, the number and size of reactors that are required is a function of the solids residence time that is required for treatment. This residence time is specific to the soil-contaminant matrix and should be determined using lab- or pilot-scale studies. Also shown in this Figure is a vapor control system that consists of activated carbon. One advantage of the liquid/solid bioslurry reactors is that it can be operated in a closed system which permits the collection and management of any offgas emissions. This cannot be accomplished during prepared-bed land treatment and only during composting if it is operated under vacuum.

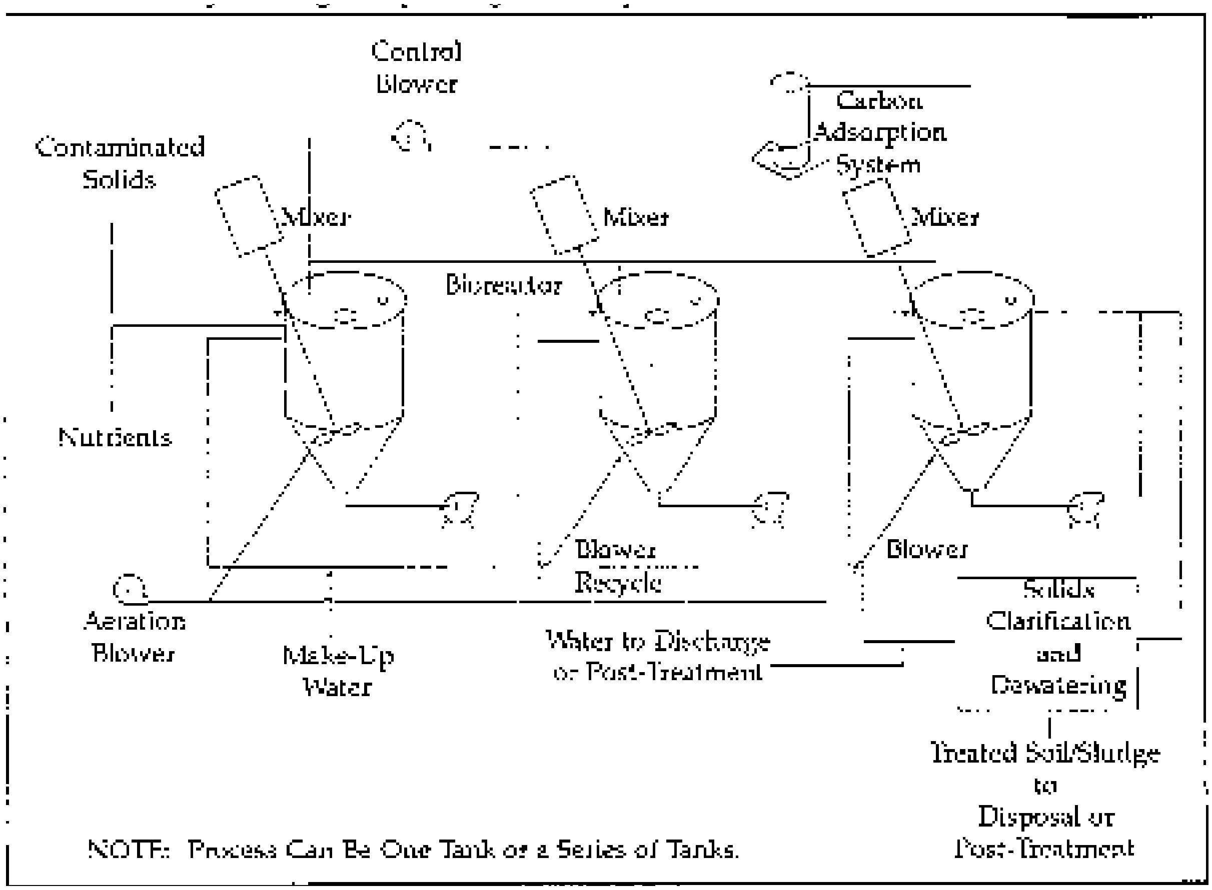


Figure A-20. Process Flowsheet for a Liquid/Solid Bioslurry System.

The clarification and dewatering step can be accomplished using gravity separation, conventional drying beds, centrifugation, stabilization, or vacuum filtration. It may even be possible to forego dewatering by incorporating the liquid/solid slurry into a prepared-bed land treatment system. This would be a viable alternative only if subsequent treatment of the solid and water was required and provided that the hydraulic loading to the prepared-bed land treatment system did not exceed the field capacity of the soil.

PERFORMANCE:

Extensive lab-scale studies have been completed using contaminated soils from MGP sites. The results of these studies have revealed a common pattern: VOC and PAH reductions are rapidly achieved within 6 to 8 weeks after which contaminant concentrations reach a plateau. The "plateau" concentrations that were achieved were quite variable and it is believed that they are dictated by the physical and chemical characteristics of the soil-contaminant matrix. Furthermore, a trend was also observed that identical treatment could be achieved in prepared-bed land treatment and liquid/solid bioslurry reactors for soils that contained less than 10 percent silts and clays (i.e., less than No. 200 U.S. Standard Sieve). However, the level of treatment was achieved much faster in the liquid/solid bioslurry reactor. For soils with greater than 10 percent silts and clays, the liquid/solids bioslurry reactor achieved more rapid and more extensive treatment than did the prepared-bed land treatment.

In all of the studies, substantial treatment of the VOCs and 2- and 3-ring PAHs was observed. Variable treatment was documented for the 4-ring PAHs and little or no treatment was recorded for the 5- and 6-ring PAHs. However, it can be argued that the "plateau" concentrations of the contaminants represent residual contamination that, regardless of its magnitude, is to tightly bound to the soil that it does not represent a risk to human health or the environment. This risk-based assessment of biological treatment argues that the treated solid has been biostabilized and is satisfactory for placement in the environment.

Recognizing that site remediation goals may be technology-driven and not risk-based, recent studies have been initiated which have added chemicals to the liquid/solid bioslurry reactors. The most common addition is Fenton's Reagent which is a mixture of iron sulfate and hydrogen peroxide. Preliminary data from these studies indicate that the addition of these chemicals may permit treatment of contaminants below their "plateau" concentrations. While lab-scale data on this process are encouraging, more studies are required at both the lab-and pilot-scale to confirm the incremental treatment that is achievable beyond the liquid/solid bioslurry treatment without additives.

REFERENCES:

Stroo, H., J. R. Smith, M. P. Coover, and R. M. Kabrick, "Bioremediation of Hydrocarbon-Contaminated Solids Using Liquid/Solids Contact Reactors," Presented at *Superfund '89*, Washington, DC, December, 1991.

Gas Research Institute, *The GRI Accelerated Biotreatability Protocol for Assessing Conventional Biological Treatment of Soils: Development and Evaluation Using Soils from Manufactured Gas Plant Sites*, GRI-92/0499, Chicago, IL, April, *1992.*

Srivastava, V. J., "Field Demonstration of Bioslurry Chemical/Biological Treatment: Enhanced Bioremediation Using Fenton's Reagent," *Town Gas Task Force Meeting Proceedings,* [Unpublished], Gas Research Institute, South Sioux City, NE, October 7-8, 1992.

PREPARED-BED LAND TREATMENT

MEDIA:

Contaminated soil and sediment.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, ammonia, and conventional pollutants such as BOD, COD, TOC.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated soil from wood treating, coal-tar distillation, coke manufacturing, petroleum refining, and chemical manufacturing industries. Lab- and field-scale studies have been conducted on contaminated soil from MGP sites.

DESCRIPTION:

Prepared-bed land treatment is an engineered unit process that involves the controlled application of contaminated soil or sediment onto a prepared soil surface and the incorporation of these residuals into the upper soil zone. The technology is generally used onsite and the contaminated soils are mixed in an above-ground process and then applied to a designated treatment area. This process is one of the older and most widely used treatment technologies for organic-contaminated soil. In particular, the technology has been used successfully throughout the United States, especially at petroleum refinery sites, and also with creosote contaminated soil and sludges.

Prepared-bed land treatment is not the indiscriminate dumping of residues on land, and it is not landfilling. A land treatment site is designed and operated to: (i) maximize residue degradation and immobilization, (ii) minimize release of dust and volatile compounds, as well as percolation of water soluble compounds, and (iii) control surface water run-on and run-off. A set of important site factors which influence the design of full-scale land treatment facilities is provided in the Table A-6.

Table A-6

KEY DESIGN AND OPERATING FACTORS FOR PREPARED-BED LAND TREATMENT

A. PERTINENT WASTE FACTORS

- Physical Composition
- Organic Contaminant Concentrations
- Metal Concentrations
- Salts
- Nutrients
- pH

B. PERTINENT SITE FACTORS

Soil Characteristics

- Topography
- Soil Texture
- Soil Moisture Content
- Cation Exchange Capacity
- Soil pH
- Soil Microorganisms
- Nutrients

Climate

- Temperature
- Precipitation

Hydrogeology

- Depth of Seasonally High Water Table.
- Depth to Useable Aquifer
- Proximity to Surface Water

C. OPERATIONAL FACTORS

Waste Application

- Hydrocarbon Loading
- Hydraulic Loading
- Frequency of Application
- Method of Application

Storm Water Management

- Run-on/Run-off Control

Waste Incorporation

- Depth of Incorporation
- Frequency of Cultivation

Soil Amendments

- Nutrients
- Moisture
- pH Control

Moisture

- Operational
- Environmental

Prepared-bed land treatment is generally an aerobic process that is managed to promote the growth of indigenous microorganisms to biodegrade contaminants and to promote immobilization of contaminants. Soil depths of 0.5 to 1.0 foot can usually be successfully treated. The contaminated soil must be handled carefully to minimize contaminant volatilization and odors while incorporating oxygen into the system by plowing, disc harrowing, or other similar methods. Blending of more highly contaminated soil with less contaminated material is sometimes necessary depending upon the type and concentration of contamination. Blending also provides additional aeration of the soils. In some cases, nutrients or fertilizer may be required to maintain the proper microbial environment and lime may be needed periodically for pH control.

The foundation of a land treatment unit can be either an impermeable liner (plastic or clay) or a packed ground surface. Both are designed to ensure minimal downward migration of contaminants to the underlying groundwater by enhancing run-off which is collected and recycled as irrigation water. The unit is the designed to prevent precipitation run-on so that water moving through and around the treatment area can be controlled. The size of a treatment unit can range from a quarter of an acre to ten acres or more. The system is engineered in a manner appropriate for the specific site situation taking into account available land area, the amount of material to be treated, the desired treatment level, and the time frame of treatment.

The viability of land treatment rests on its capability to reduce or immobilize the contaminants in the soil to acceptable levels, while controlling contaminant emissions (i.e., volatilization and leachate) from the treatment unit to below levels that could cause public health or environmental concern.

PERFORMANCE:

It has been generally observed that the more desorbable and more water soluble contaminants in soil are biodegraded at a faster rate and to a greater extent than the less desorbable and less soluble contaminants. In addition, studies have shown that prepared-bed treatment of soils is capable of detoxifying and immobilizing soil contaminants to where they no longer represent a source of contamination to the groundwater or atmosphere.

A properly designed and operated prepared-bed land treatment facility was reported to provide the following contaminant reductions:

- 40 percent of total benzene extractables and
- 61 to 80 percent of total PAH compounds, including 80 to 90 percent of 2-ring PAHs, 82 to 93 percent of 3-ring PAHs, and 21 to 47 percent of 4-ring to 6-ring PAHs.

In addition, the treatment Converted ammonia to nitrate, degraded free- and weak-acid dissociable cyanide, and immobilized heavy metals.

Extensive lab-scale studies of prepared-bed land treatment have been conducted on MGP site soil using pan reactors and more recently, a field demonstration was conducted at an MGP site in the mid-western United States. These studies indicate generally good treatment of VOCs and 2- and 3-ring PAHs. Treatment of 4-ring PAHs is more variable and little treatment of 5- and 6-ring PAHs occurred. These observations lead to the conclusion that the extent of treatment that can be achieved for any given soil-contaminant matrix is a strong function of the chemical distribution of contaminants and the characteristics of the soil itself. Typically, better treatment has been observed in sandy soils than in soils with high silt or clay contents.

REFERENCES:

Brown, K. W., et al., *Land Treatability of Refinery and Petrochemical Sludges,* EPA Project Summary, EPA-600/52-83-074, November, 1983.

ETR, *Land Treatment Practices in the Petroleum Industry,"* American Petroleum Institute, Washington, DC, 1983.

Loehr, R. C., et al., *Land Treatment of an Oily Waste-Degradation, Immobilization, and Bioaccumulation ,"* EPA/600/285/009, February, 1985.

Gas Research Institute, *The GRI Accelerated Biotreatability Protocol for Assessing Conventional Biological Treatment of Soils: Development and Evaluation Using Soils from Manufactured Gas Plant Sites,* GRI-92/0499, Chicago, IL, April, 1992

Gas Research Institute, *Biological Treatment of Soils Containing Manufactured Gas Plant Residues,* GRI-90/117, Chicago, IL, February, 1990.

Donovan, D. and M. Jampole, "Solubilize It—And They Will Come," *GRID,* Gas Research Institute, Chicago, IL, pgs. 13-15, Fall, 1993.

SOIL AERATION

MEDIA:

Contaminated soil.

TARGET CONTAMINANTS:

VOCs and naphthalene.

RELEVANT INDUSTRIAL EXPERIENCE:

Limited use at hazardous waste sites.

DESCRIPTION:

Soils contaminated with volatile compounds are excavated and placed in piles four to five feet high over an air distribution system. The distribution system consists of parallel slotted PVC pipes which are capped at the far end of the pile. Pipes may also be placed parallel in the pile as required to accelerate stripping. The piles should be constructed over a paved area with a drainage collection system to prevent the escape of contaminated leachate. A cover is recommended during periods of rainfall to prevent significant leaching of contaminants.

Forced-air strippers use an air blower to force fresh air through the pipes and into the pile. Air contaminated with VOCs is forced from the pile and released into the atmosphere. Vacuum strippers use a vacuum pump to draw fresh air into the pile. Air contaminated with VOCs is drawn through the vacuum pump and into a treatment system before it is released to the atmosphere.

Critical operating parameters include air temperature, air flow rate, and air/soil contact time. Operating conditions may be modified to accommodate site conditions, soil conditions, weather, and the desired site cleanup levels.

PERFORMANCE:

A forced soil aeration test achieved 90 to 99 percent removal of 1,000 ppm of VOCs in some areas of a contaminated pile. Other areas achieved less removal. Another test showed VOC reduction from 100 to 15 ppm in some areas; lesser reductions occurred in other areas. These results suggest that preferential air movement occurs in the piles and results in non-uniform treatment. Areas with little void space receive less treatment than those with larger void space. For soils with high concentrations of VOC, some form of post treatment of the soil may be required following aeration.

REFERENCES:

Evans, Jeffrey C., *Proceedings of the Nineteenth Mid-Atlantic Industrial Waste Conference - Toxic and Hazardous Wastes,* ISSN 0894-0290, 1987.

STABILIZATION

MEDIA:

Contaminated soil, sediment, purifier box wastes, and free-phase hydrocarbons.

TARGET CONTAMINANTS:

PAHs, metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated solids from the wood treating, petroleum refining, and chemical manufacturing industries. Full-scale stabilization of free-phase hydrocarbons and contaminated solids from MGP sites has occurred although there is little documentation of the results of these applications.

DESCRIPTION:

Stabilization refers to the process by which contaminant mobility is decreased through physical and/or chemical means. "Stabilization" has been used synonymously with a variety of terms including immobilization, encapsulation, fixation, and solidification. Specific definitions have been assigned to each of these terms by the U.S. Environmental Protection Agency and others to differentiate between the fundamental physical and chemical processes that take place. For the purposes of this document, stabilization is used generically to refer to all such technologies and processes.

Ex situ stabilization deals with the excavation and subsequent partial or full immobilization of the contaminants. Excavation and partial immobilization is useful for improving waste handling characteristics and solidifying liquid wastes prior to disposal in a secure landfill. Excavation and full immobilzation is generally used to convert residuals to a solid mass with more complete immobilization of soluble contaminants. Figure A-21 provides a process schematic of an *ex situ* stabilization process. The equipment required for *ex situ* treatment typically includes standard cement mixing and handling equipment; however specialized and proprietary equipment may be used. Typical stabilizing agents include portland cement, cement kiln dust, lime kiln dust, flyash, soluble silicates, and epoxy and polyester resins. Some commercial companies have their own proprietary mixtures which are usually some combination of these agents. Once the stabilizing agent is added, setting and curing time can take up to several days or longer.

The stabilization process can be performed on-site or at off-site facilities. Since the equipment is quite mobile, the on-site treatment can be conducted with relative ease. On-site treatment would require space for the equipment and a staging area for curing the stabilized material.

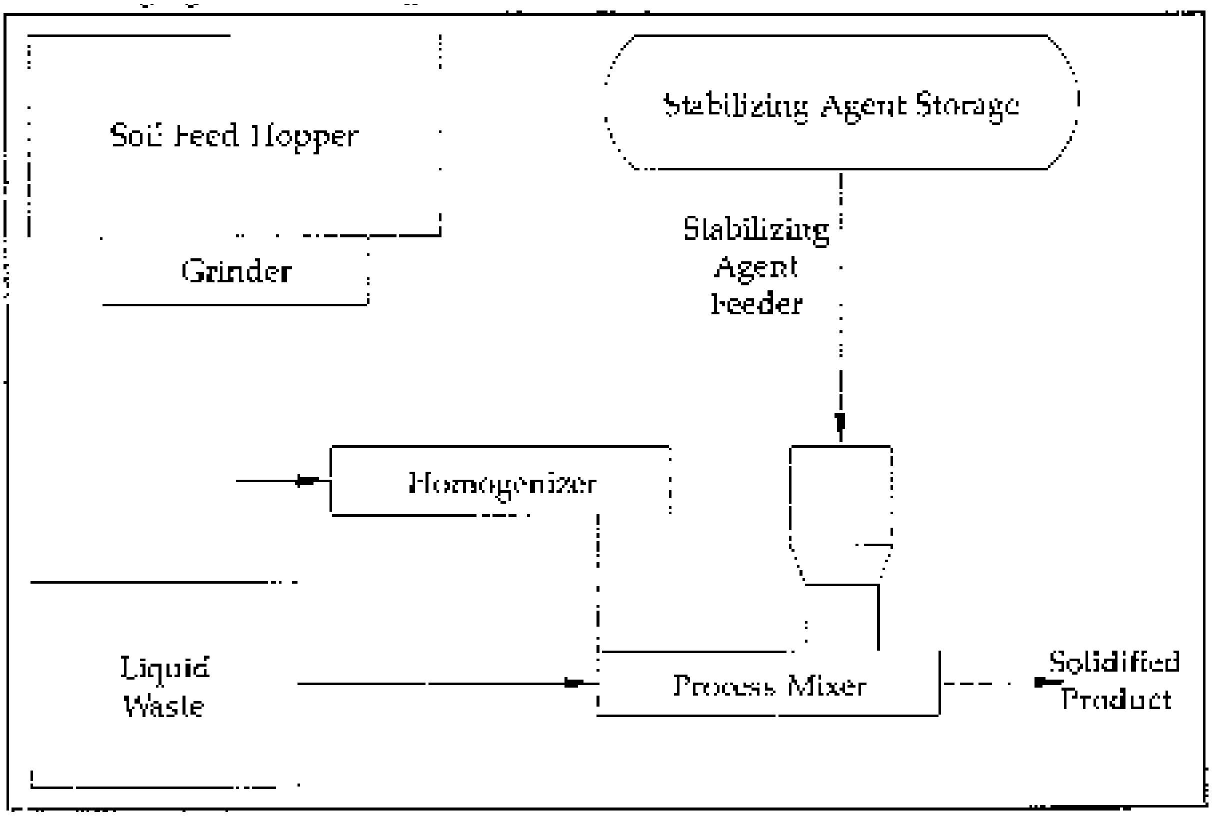


Figure A-21. Process Flowsheet for *Ex Situ* Stabilization.

PERFORMANCE:

The performance of stabilization processes has traditionally been determined by measuring the concentration of EPA designated contaminants in an aqueous extract of a treated sample. However, there is general concern that the EPA tests, which require that the sample be crushed prior to extraction, is not representative of the actual situation of a monolith that is placed within a landfill. Nevertheless, vendors have reported leachate concentrations of contaminants as low as EPA drinking water standards for a variety of wastes and stabilizing formulations. Organic contaminated solids have been stabilized to the extent that there have been significant reductions in the contaminants that leach from the waste. In addition, the performance of this technology, as determined by achieving a solid material (no free liquid) with characteristics suitable for placement in a landfill, has been demonstrated on both inorganic and organic contaminated solids. However, performance is very waste dependent and formulations to successfully stabilize organics are specialized. Lastly, performance as measured by long term stability of the contaminants in a landfill environment has not been well documented.

REFERENCES:

Cullinane Jr., M. J., et al., *Handbook for Stabilization/Solidification of Hazardous Wastes,* EPA/580/2-86/001, U.S. Environmental Protection Agency.

Hill, R. D., *Stabilization/Solidification of Hazardous Waste,* EPA/600/0-86/028, U.S. Environmental Protection Agency.

THERMAL DESORPTION

MEDIA:

Contaminated soil, sediment, and purifier waste.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Lab-, pilot-, and full-scale applications to contaminated soil from the wood treating, coal-tar distillation, and petroleum refining industries. Comprehensive lab- and pilot-scale studies were completed on contaminated soil from MGP sites by GRI and a full-scale demonstration test was completed in late *1993* on an MGP site in the State of New York. A full-scale site remediation of an MGP site in New Jersey is planned using thermal desorption in 1994.

DESCRIPTION:

Thermal desorption refers to the separation of chemical constituents that can be volatilized from nonvolatile solids, such as soil, by heating the soil to elevate the vapor pressure of the chemical so that it diffuses through and volatilizes from the solid into the gas phase. Desorption temperatures typically range between 200°F to 900°F which is much lower than the temperature required for thermally induced decomposition reactions (e.g., oxidation, pyrolysis) to occur (i.e., 1500°F to 3000°F); however, temperatures as high as 1800°F to 2000°F can be achieved in some units under a nitrogen atmosphere to preclude combustion reactions. The lower temperature units achieve removal of the VOCs and many of the PAHs. The higher temperature units also remove some of the higher molecular weight organic contaminants as well as the more volatile metals such as arsenic. At these temperatures, many of the metals that are not volatilized remain bound in the treated soil that exits the desorber. The lower temperatures and/or lack of oxygen, distinguish thermal desorption from incineration, in which combustion (destruction) of the contaminants is intended.

There are three basic thermal desorption process options for treating contaminated solids which all utilize a desorber as the initial separation step but different off-gas treatment systems. Each of these three options can employ different process configurations and types of equipment for both the desorber and off-gas treatment. The primary desorber configurations include rotary kilns and auger screws. The rotary kilns can be both direct-fired and indirect-fired. The direct-fired systems use a fuel burner as the heat source which either fires directly into the primary solid heating chamber or heats air which directly contacts the contaminated solid. The indirect-fired systems generally use a heat transfer medium such as hot combustion gas or hot oil to heat one side of a metal surface that conducts the heat to the contaminated solid. The auger configurations provide only indirect heating of the solids. The selection of the appropriate design and size of unit for each site will depend heavily upon such factors as the volume of soils that are present at the site, the soil heat content and moisture content, the nature of the contaminants, and the permitting constraints of the site, to name a few.

The three potential off-gas configurations include:

- Collection of the volatilized moisture and organics using conventional condensing equipment (direct or indirect). This generally requires isolation and off-site disposal of the condensate unless it can be recycled for chemical or fuel value. In this mode of operation, the process effectively reduces the volume of the contaminated media that requires final treatment or disposal, the recovered hydrocarbon condensates are placed into commerce, and the process may qualify for a recycle exemption under the existing regulatory framework. Such an exemption eliminates the need to obtain a RCRA Hazardous Waste Part B Permit should the untreated solid be classified as a hazardous waste.
- Incineration at 1500°F to 3000°F or catalytic oxidation followed by an air pollution control system and offgas stack.
- Discharge to the atmosphere without treatment. This would only be considered for nontoxic contaminants present at very low concentrations although normally the use of activated carbon represents a minimum treatment requirement prior to discharge.

The selection of the most appropriate process configuration depends on many factors, including site location and characteristics, regulatory and political attitudes, concentration and type of contaminants, and size and complexity of the remedial action (e.g., how much contaminated soil, what other wastes require treatment or disposal). For example, thermal desorbers have been shown to be effective for the removal of complexed cyanide from purifier box wastes. However, these materials may also contain significant quantities of sulfur since the purpose of the purifier boxes was to remove hydrogen sulfide from the manufactured gas. As such, it is likely that the desorption of the cyanides should be accomplished using indirect-fired desorption units with nitrogen atmospheres and no afterburners to ensure that sulfur dioxide is not formed. Sulfur dioxide emissions potentially pose permitting difficulties in many regions of the country and their avoidance may be required to obtain approvals for a site remediation and/or to reduce its costs.

Treated material discharged from the desorber is cooled as necessary and containerized or placed in piles until sample analysis confirms that it has met cleanup criteria. At this time, it may be possible to redeposit the treated material into the excavated area of the site. This onsite management option is reasonably straight-forward above the groundwater table; however, it is somewhat more complicated below the groundwater table because the potential exists for the recontamination of the treated soils should it come into contact with contaminated groundwater or other media. This logistical issue and regulatory acceptance of placement of the treated solids must be carefully analyzed as part of any onsite management scheme.

PERFORMANCE:

Limited operation of onsite thermal desorption processes has occurred on MGP sites in the U.S., however, two large fixed-base facilities have been used for treating contaminated soil from MGP sites as well as other contaminated sites in the Netherlands. The units were designed, built, and operated by Ecotechniek and NBM Bodemsanering and have been operating since the early 1980s. While both companies use rotary kilns as their primary treatment Unit, NBM uses an indirect-fired, co-current system whereas Ecotechniek uses a direct-fired, countercurrent system. The facilities operate their kilns at about 900° to 1100°F and their offgas afterburners at 1600° to 2900°E Approximately 470,000 tons of contaminated soil have been treated in the NBM facility and nearly 1,430,000 tons in the Ecotechniek unit. Both units have achieved reductions of over 98% in total petroleum hydrocarbons, BTEX, PAHs, and cyanide, producing treated soils with final concentrations of less than 50 ppm, 0.2 ppm, 1.0 ppm, and 5.0 ppm respectively.

The Gas Research Institute also conducted a number of laboratory- and pilot-scale studies on thermal desorption using contaminated soils from MGP sites in the United States. The results of these efforts have been summarized in three reports [GRI, 1988; GRI, 1989a; and GRI, 1989b]. For the most part, the results of these studies paralleled those of the full-scale units in the Netherlands but at somewhat lower operating temperatures and higher residence times. The GRI tests subjected the soils to temperatures of 550° to 750°F with residence times of 10 to 30 minutes and achieved reductions in total PAHs and cyanide that were similar to those achieved in the Netherlands.

More recently, two full-scale thermal desorption systems were installed at two MGP sites on the east coast to treat several MGP site residuals. The .first is a demonstration program utilitizing a direct-fired rotary kiln with an offgas afterburner. The test results of this demonstration program will be issued jointly by EPRI and the Niagara Mohawk Power Corporation. The second is a full-scale MGP site remediation project in New Jersey. The system installed for this project consists of an electrically heated auger that volatilizes the contaminants after which they are condensed from the overhead gas and then recycled as liquid hydrocarbons. This project includes thermal desorption of approximately 16,000 tons of relatively high concentration tars from two subgrade gas holder tanks and an additional 100,000 tons of lower. concentration waste in the unsaturated zone surrounding the tanks.

REFERENCES:

Noland, J. W., et. al., "Low Temperature Thermal Stripping of Volatile Compounds," *Proceedings of the National Conference of Hazardous Wastes and Hazardous Materials,* Atlanta, GA, March 4-6, pp. 229-232, 1986.

Roy F. Weston, Inc., "Economic Evaluations of Low Temperature Thermal Stripping of Volatile Organic Compounds from Soil," Prepared for U.S. Army Toxic Materials Agency, Aberdeen Proving Ground, MD, August, 1986.

Gas Research Institute, 1988, *Laboratory Study of Thermal Desorption Treatment of Contaminated Soils from Former Manufactured Gas Plant Sites,* [Topical Report No. GRI-88/0161], Chicago, IL, August.

Gas Research Institute, 1989a, *Engineering-Scale Evaluation of Thermal Desorption Technology for Manufactured Gas Plant Site Soils,* [Topical Report No. GRI-89/0271], Chicago, IL, August.

Gas Research Institute, 1989b, *Laboratory Study of the Effect of Thermal Treatment on the Metal Leaching Characteristics of Soils from Manufactured Gas Plant Sites,* [Topical Report No. GRI-89/0243], Chicago, IL, August. El

IN SITU CONTAINMENT

GROUT BARRIERS

MEDIA:

Free-phase. hydrocarbons, purifier box wastes, and contaminated soil and water

TARGET CONTAMINANTS:

All contaminants provided that suitable materials of construction are used.

RELEVANT INDUSTRIAL EXPERIENCE:

Some use at hazardous waste sites.

DESCRIPTION:

Grout barriers may be applied to soil and rock under favorable conditions to provide a bottom cutoff to control the vertical migration of contaminated groundwater and leachates, including NAPL. The only practical manner of constructing a horizontal-bottom barrier *in situ* is by injection of low permeability cementitious or chemical materials into soil voids or rock fractures. These barriers are constructed in the saturated zone which facilitates distribution of the slurry material. Generally, this process requires extending boreholes vertically through waste or contaminated soil deposits to the subsurface horizon which has been designated for grouting. As such, significant precautions must be taken to minimize the further spread of contamination duping this process. Similar to the construction of vertical barriers in rock, the spacing between adjacent injection boreholes must be designed to ensure an overlapping pattern of grout at the appropriate subsurface horizon. Where ground conditions are suitable, the bottom barrier can be sloped to permit collection of leachates by gravity flow. In general, horizontal barriers must be used in combination with other containment and/or interception methods to achieve an effective barrier system. Figure A-22 illustrates the installation of a grout barrier and the resulting displacement of a "block" of contamination.

PERFORMANCE:

Grout barriers can be used to control vertical waste migration. Control of vertical migration in combination with groundwater or leachate extraction, providesa means to prevent vertical contaminant flow. Successful application of grout barriers is limited to favorable site geologic conditions, especially in the subsurface horizon that is targeted for treatment.

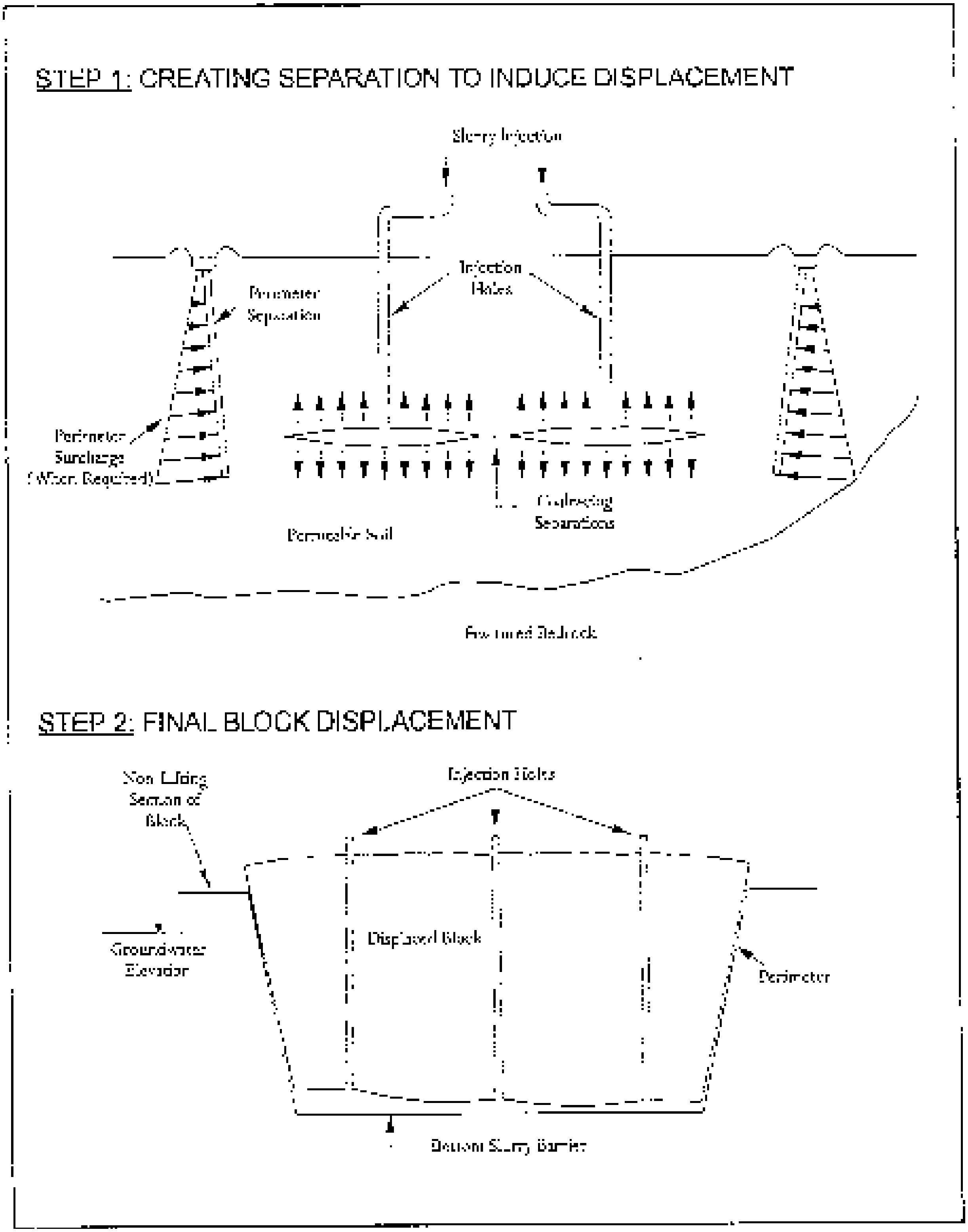


Figure A-22. Process Flowsheet for Grout Barriers.

Performance of grout barriers may be impacted by improper quality control during construction, chemical attack by contaminants and continuity of the barrier over large areas of application.

There are no recorded applications of grout barriers to MGP sites. However, given the presence of DNAPLs (i.e., NAPLs that are denser than water) at many of the MGP sites, grout barriers may prove to be very important to some site remediation efforts.

REFERENCES:

May, J. H., R. J. Larson, P. G. Malone, J. A. Boa, and D. L. Bean, *Grouting Techniques in Bottom Sealing of Hazardous Waste Sites,* Texas A&M University, College Station, TX, prepared for the U.S. Environmental Protection Agency, Hazardous Waste Engineering Report Laboratory, Cincinnati, OH, 1986.

GROUT CURTAIN

MEDIA:

Free-phase hydrocarbons, purifier box wastes, and contaminated soil and water.

TARGET CONTAMINANTS:

All contaminants provided that compatible materials of construction are used.

RELEVANT INDUSTRIAL EXPERIENCE:

Some use of hazardous waste sites.

DESCRIPTION:

Grout curtains are subsurface barriers created in unconsolidated materials by pressure injection of grout. They can be utilized in various configurations including:

- semicircular placement downgradient of the waste material to prevent migration;
- semicircular placement upgradient of the waste material to prevent groundwater contact with contaminated media and the subsequent leaching of the contaminants to the groundwater; and
- circumferential placement surrounding the waste material to ensure isolation (e.g. at a permitted landfill).

However, placement of grout in the saturated zone downgradient of the source can lead to problems associated with the setting and durability of the barrier.

Design of a grout curtain is based on many technical and site-specific which factors. Some of the more important of these considerations are: (1) the site hydrogeology which generally determines the feasibility of using grout injection to create a physical barrier; (2) the grout viscosity which determines the penetration rates and pressures required for its injection; (3) the chemical compatibility of the grout with the site contaminants which is required to ensure the long-term integrity of the barrier; and (4) the permeability of the grout curtain which determines its potential to permit the passage of leachate beyond the containment area. It should be noted that the permeability of the barrier can be significantly increased by small gaps resulting from non-penetration of grout during injection.

Several methods can be used for injection of grout. These include:

- **Stage Up Method**. The borehole is drilled to full depth. As the drill is withdrawn, an appropriate amount of grout is injected into the hole.
- **Stage Down Method**. The borehole is drilled in stages. After the first stage is drilled, the drill is withdrawn and grout is injected. The borehole is redrilled through the grout into the second stage. The drill is withdrawn and grout is injected. This process is repeated to the full depth of the hole.
- **Grout Port Method**. A slotted injection pipe with a cement/mortar jacket is placed in the hole. Rubber sleeves cover the slots to prevent backfeeding of the grout. A brief pulse of high pressure water is injected into the pipe to rupture the jacket. Grout is then pumped through the pipe, out of the cracked jacket, and into the soil.
- **Vibrating Beam Method**. An I-beam is vibrated into the soil to a desired depth. As it is removed, grout is injected from nozzles in the bottom of the beam, filling the cavity. The beam is reinserted less than one beam width to the side, leaving a suitable overlap to ensure continuity.

PERFORMANCE:

Grout curtains are more costly than slurry walls and are much more unreliable due to unfilled gaps and grout shrinkage. A field test of two chemical grouts in medium sands revealed significant problems in forming a continuous barrier due to non-coalescence of columns in adjacent holes and shrinkage of the grout. Generally speaking, grout applications are not as effective as other physical barriers in the unconsolidated geologic materials.

REFERENCES:

USEPA Hazardous Waste Engineering Research Laboratory, *Technology Briefs: Data Requirements for Selecting Remedial Action Tech n o fogy* Cincinnati, OH, EPA/600/2-87/001, January, 1987.

Spooner, P.A., R.S. Wetzel and W.E. Grube, USEPA, "Land Disposal of Hazardous Waste," *Slurry Trench Construction Pollution Migration CutOff Walls,* EPA/600/9-83/018, September, 1983.

USEPA Office of Emergency and Remedial Response, *Remedial Action at Waste Disposal Sites,* Washington, D.C., EPA/625/6-85/006, October, 1985.

HYDRAULIC CONTROL

MEDIA:

Contaminated groundwater and free phase hydrocarbon.

TARGET CONTAMINANTS:

All site contaminants.

RELEVANT INDUSTRIAL EXPERIENCE:

Extensive applications for groundwater management at both construction and environmental sites.

DESCRIPTION:

Hydraulic controls prevent the offsite migration of contaminated groundwater or free phase hydrocarbons by altering the subsurface flow patterns of these liquids at a site. The controls usually consist of well points, suction wells, or ejector wells which are installed within the site boundaries or at the site perimeter. Alternatively, subsurface drainage systems can be used which include ditches, trenches, and channels. The latter are typically used for sites which have shallow water tables and/or the presence of a floating free phase hydrocarbon.

In the case of a well point system, a series of wells are placed downgradient from the site to intercept groundwater flow before it leaves the site boundaries. The wells are spaced to ensure an overlapping drawdown envelope so that the entire groundwater flow is captured; however, this also can result in the capture of offsite groundwater that is drawn into the site by the well point withdrawal system. For the recovery of free phase hydrocarbons, it is necessary to ensure that the well points intercept the nearest confining layer to capture DNAPLs and the surface of the groundwater table to capture LNAPLs.

The proper design of a hydraulic control system requires a thorough knowledge of the subsurface conditions at a site. Some of the more important information which should be understood is the hydraulic gradients, the permeabilities of the soil strata, and the heterogeneity of the subsurface geologic units. The use of subsurface flow and contaminant transport models is required to analyze this subsurface information and to complete the design of the hydraulic control system.

Hydraulic controls can cause subsidence of nearby structures because of soil consolidation. They can also affect other neighboring wells that draw from the same water table and cart affect surrounding water sources and wetland areas. Lastly, the groundwater that is removed must be properly managed which often includes treatment followed by discharge to a surface water body or Publicly Owned Treatment Works (POTW).

PERFORMANCE:

While many hydraulic control systems have been utilized to manage groundwater at contaminated sites, there are limited data available to evaluate their performance. However, it is suspected that good performance can be achieved providing that the subsurface conditions at the site are well understood and that no anomalies in the subsurface geology exist, e.g., the presence of substantial faults or bedrock fractures.

REFERENCES:

Electric Power Research Institute, *Assessment of Selected Technologies for Remediation of Manufactured Gas Plant Sites,* [Final Report No. GS-7554], Palo Alto, CA, October, 1991.

SHEET PILES

MEDIA:

Free-phase hydrocarbons, purifier box wastes, and contaminated soft, sediment, and water.

TARGET CONTAMINANTS:

All contaminants provided that suitable materials of construction are used.

RELEVANT INDUSTRIAL EXPERIENCE:

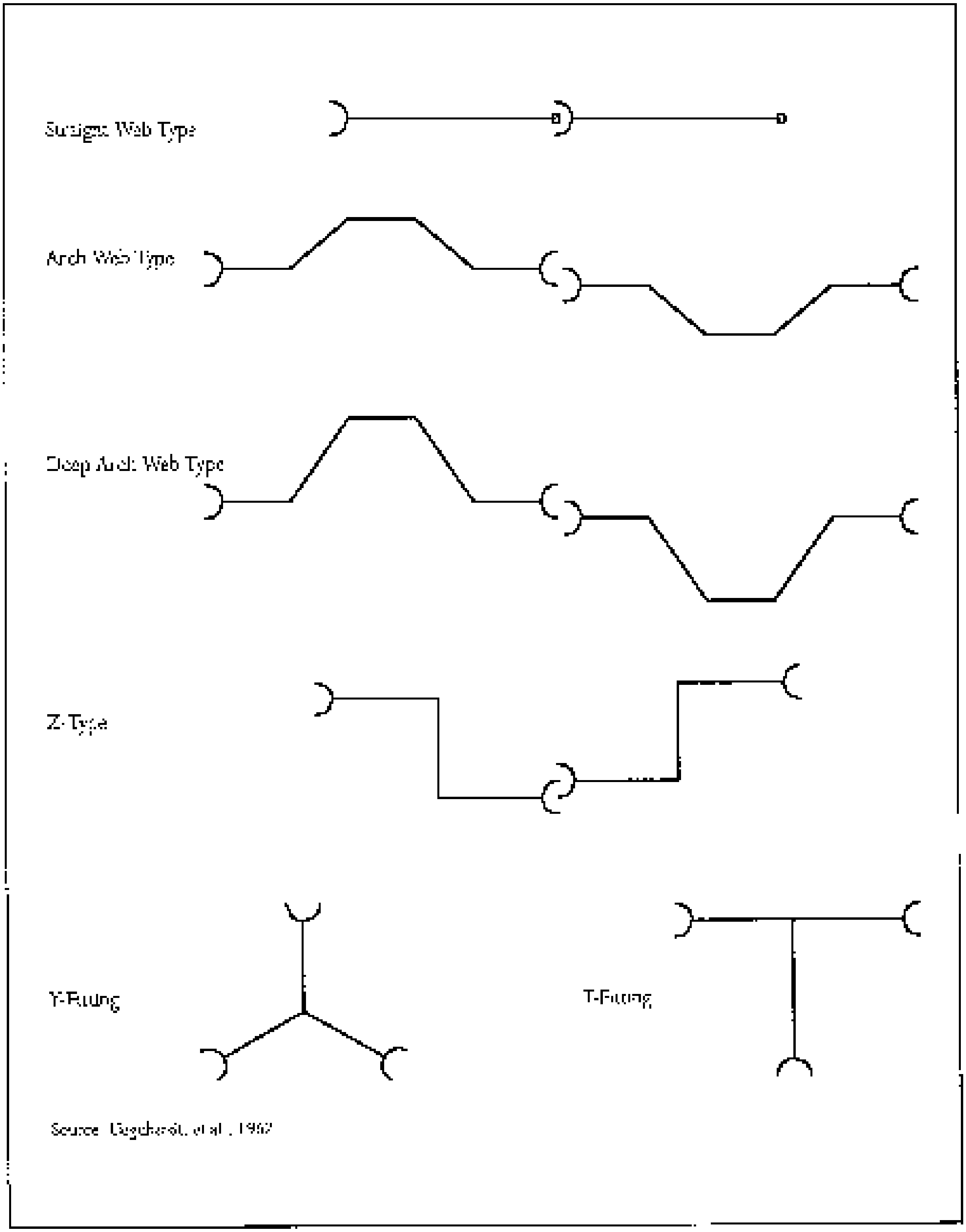
Extensive use at general construction sites with increasing use at hazardous waste sites. Limited use at MGP sites.

DESCRIPTION:

Sheet piles are used to provide a barrier to control the lateral migration of contaminated fluids. Sheet piles can be made of wood, pre-cast concrete, or steel. Wood is an ineffective barrier against water and is rarely used. Pre-cast concrete is primarily used where great strength is required. Steel, .being the most effective in groundwater cut-off and cost, is the most common material of construction.

Construction of a sheet pile wall is initiated by interlocking individual sheets of pilings at their edges. Typical piling shapes are shown in Figure A-23. The interlocked piles are then driven, in sections, to the desired depth. Drop or vibratory hammers are used to drive the piles into place. Heavy equipment is preferred since lightweight equipment drives slower and can distort the top of the piling. A cap block or driving head is usually placed on top of the piling while being driven to prevent damage from the hammer. Once installed, soil fines are washed into the edge interlocks to form a low permeability barrier. Depending on the texture of the soil and groundwater flow rates, the edge interlocks may never completely seal. In this case, the seams can be grouted, but it is a costly procedure.

Due to costs and the unpredictability of wall integrity, sheet piles are seldom used except for temporary dewatering (e.g., such as is required during site excavations) or erosion protection. The main design consideration for sheet pilings is the site hydrogeology. These site-specific factors determine the size and shape of the individual sheet pilings that are used and the necessity for a water-tight seal. Furthermore, the soil type will also dictate the ease of installation.



Source: [illegible], et al., 1982

Figure A-23. Example of Sheet piling Shapes and Interlocks.

For example, rocky soils can render sheet pilings ineffective by damaging or deflecting the barrier as it is installed.

PERFORMANCE:

The performance life of sheet piles range between 7 and 40 years, depending on the soil in which it was installed. Sheet piles have been successfully implemented in soils ranging from well-drained sands to impervious clays with the pH of the soil ranging from 2 to 9. Additional protection of sheet piles from soil corrosion include hot-dip galvanizing or polymer-coating, or cathodic protection.

The use of sheet piles at MGP sites have been primarily during soil excavation activities. In addition, they have been considered as a means to isolate treatment cells within surface water bodies. This latter application is related to the *in situ* treatment of sediments in an harbor using biological oxidation. Few, if any applications have been for long-term management of subsurface contaminant migration.

REFERENCES:

USEPA Hazardous Waste Engineering Research Laboratory, *Tech no fogy Briefs: Data Requirements for Selecting Remedial Action Technology,* Cincinnati, OH; *EPA/600/2-87/001,* January, 1987.

Spooner, P.A., R.S. Wetzel and W.E. Grube, "Disposal of Hazardous Waste," *Slurry Trench Construction Pollution Migration Cut-Off Walls,* EPA/-600/9-83/018, U.S. Environmental Protection Agency, September, 1983.

USEPA Office of Emergency and Remedial Response, *Remedial Action at Waste Disposal Sites,* Washington, D.C., EPA/625/6-85/006, October, 1985.

SLURRY WALL

MEDIA:

Free-phase hydrocarbons, purifier box wastes, and contaminated soft and water.

TARGET CONTAMINANTS:

All contaminants provided that suitable materials of construction are used.

RELEVANT INDUSTRIAL EXPERIENCE:

Often used at hazardous waste sites in combination with other technologies (e.g., cap/cover and groundwater pumping and treatment). Full-scale applications at MGP sites have been implemented.

DESCRIPTION:

Slurry walls are used to provide a barrier to control the lateral migration of contaminated fluids. Slurry walls are designed to impede or direct migration of contaminants and are constructed of low permeability materials which are compatible with the waste constituents.

An example of a circumferential slurry wall enclosing a waste pile is illustrated in Figure A-24. The slurry wall is constructed around the waste material by excavating a vertical trench that is filled with a slurry at the time of excavation. The slurry, (usually soil and bentonite) acts like a drilling fluid, hydraulically shoring the trench to prevent collapse and, at the same time, forming a filter cake on the trench walls to reduce water losses into the surrounding area. In some cases, the slurry is comprised of a mixture of portland cement, bentonite, and water. After excavation, this mixture sets up in place to form a completed barrier.

Slurry walls can be utilized in many ways including:

- semicircular placement downgradient of the waste material to prevent migration;
- semicircular placement upgradient of the waste material to present groundwater contact with the contaminated media and the subsequent leaching of contaminants from the media into the groundwater; and
- circumferential placement surrounding the waste material to ensure isolation (e.g. at a permitted landfill).

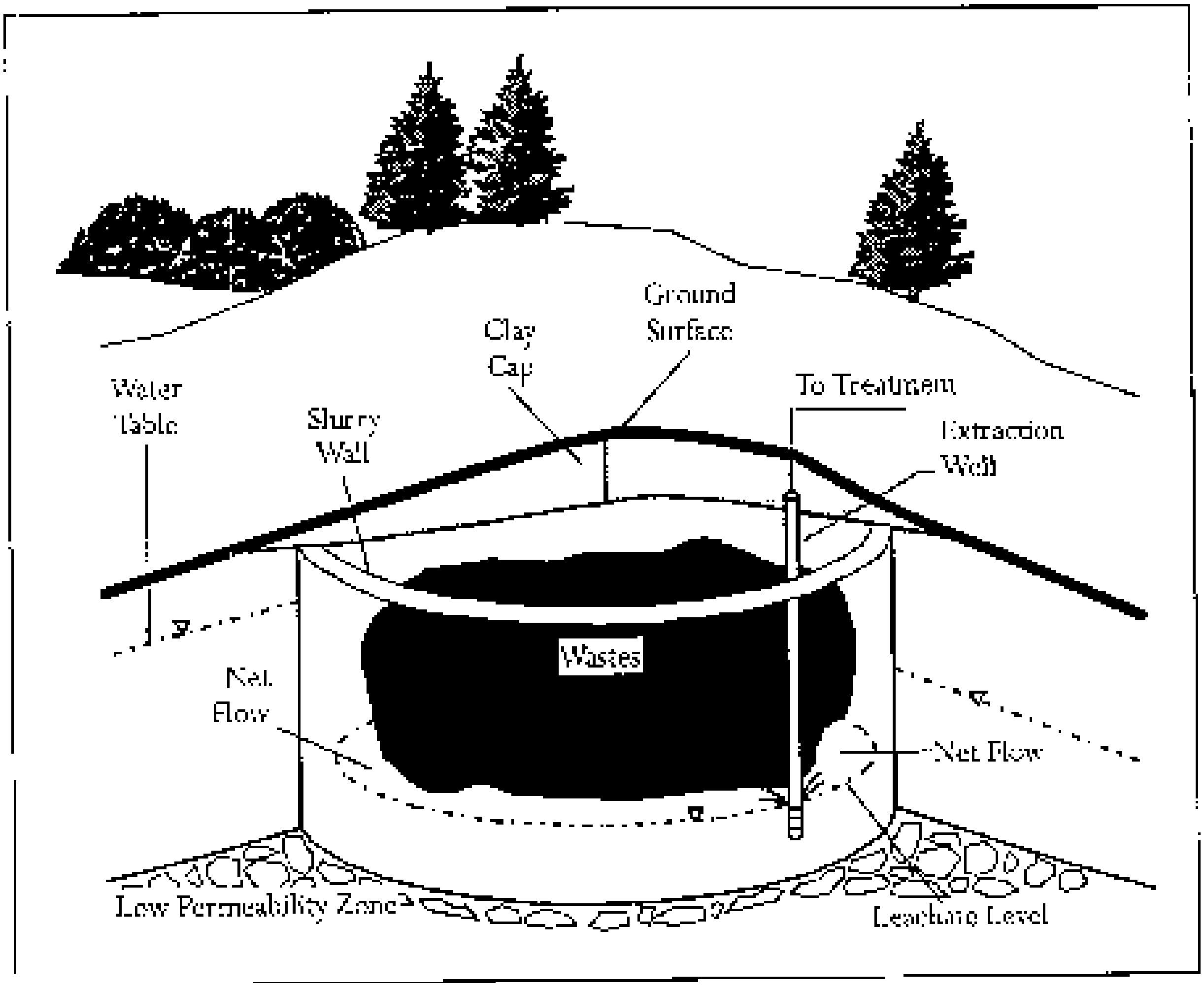


Figure A-24. Cross-Section of Circumferential Slurry Wall.

Slurry wall design is based on the hydrogeology of the site, the reactivity of site contaminants with the slurry wall materials, and the desired permeability of the slurry wall. The lowest permeability slurry walls usually contain 20 to 40% fines.

PERFORMANCE:

Slurry walls have been used at MGP sites in at least three instances including applications in the states of Pennsylvania, New York, and California. In two of the cases, groundwater withdrawal followed by surface treatment has also been implemented. The performance of the slurry walls in these applications has not been formally documented although there have been reports that breaches of the walls by the subsurface fluids have occurred.

The performance of slurry walls may be impacted most by improper quality control during construction, chemical attack (e.g. desiccation) by contaminants and subsequent loss of integrity, and intrusion by man. However, it is difficult to make an in-place assessment of the permeability of the wall as well as its overall integrity. As such, most performance assessments require the collection of extensive upgradient and downgradient monitoring data to permit a comparison of the presence of NAPL and the overall groundwater quality.

REFERENCES:

USEPA Hazardous Waste Engineering Research Laboratory, *Technology Briefs: Data Requirements for Selecting Remedial Action Technology,* Cincinnati, OH; EPA/600/2-87/001, January, 1987.

Spooner, P.A., R.S. Wetzel and W.E. Grube, "Disposal of Hazardous Waste," *Slurry Trench Construction Pollution Migration Cut-Off Walls,* EPA/*-600/9-83/018,* U.S. Environmental Protection Agency, September, 1983.

USEPA Office of Emergency and Remedial Response, *Remedial Action at Waste Disposal Sites,* Washington, D.C., EPA/625/6-85/006, October, 1985.

FREEZE WALL

MEDIA:

Contaminated soil, purifier box wastes, and free phase hydrocarbons.

TARGET CONTAMINANTS:

All site contaminants.

RELEVANT INDUSTRIAL EXPERIENCE:

Extensive applications for groundwater control and excavation support in the construction industry. More recently it has been considered for use in environmental applications. No applications have been applied to MGP sites although one is currently under construction and will be operational in 1994.

DESCRIPTION:

Artificial ground freezing involves the circulation of a refrigerated coolant through a series of subsurface pipes to extract heat, thus converting the soil water to ice, creating a strong, watertight material. The material is so strong that it is routinely used as the only method of groundwater control and soil support for the construction of shafts , hundreds of feet into water-bearing soils. For environmental applications, artificial ground freezing can be used to form frozen earth barriers to prevent the migration of contaminated groundwater. The barrier is often used to contain contamination during remediation activities on a temporary basis or can be installed for long-term use. Of particular note is that the actual geometry of the barrier wall is extremely flexible, permitting its location near existing structures, utilities, and right-of-ways.

The single most important component of a ground freezing system is the subsurface refrigeration system which consists of a series of refrigeration pipes, installed with various drilling techniques. The quantity, spacing, depth, and size of the refrigeration pipes are unique to each site and are determined on the basis of the thermal and hydraulic properties of the soils, construction schedules, and cost effectiveness. Within the freeze pipes, a smaller diameter feed pipe is installed permitting the downward circulation of the cooling medium which then flows to the surface through the annulus of the larger pipe. The cooling medium that is used varies depending on the required application. Where very rapid freezing is required, liquid nitrogen is used with temperatures well below -150°C. For most applications, however, a secondary coolant such as calcium chloride (brine) or ethylene glycol is used. The secondary coolant is chilled using large portable refrigeration plants which employ ammonia as the primary refrigerant. These refrigeration units are typically mounted on conventional over-the-road trailers and are electrically powered using commercially available electricity or diesel generators. Once the system has been drilled and installed, it operates continuously as a closed system requiring constant monitoring with occasional plant adjustment. After the initial freezing has been completed and the frozen barrier is in place, the required refrigeration capacity is significantly reduced to maintain the frozen barrier.

The preliminary design of the barrier walls must consider the subsurface soil properties. At a minimum, it is important to identify the site-specific soil strata, the contaminant concentrations in each strata, the index properties of the soil including unfrozen water content and grain size distribution, permeabilities of subsurface strata from field tests, and seasonal ground water levels. Some important considerations that should not be overlooked are listed below:

(1) The spacing between refrigeration pipes and the depth of each pipe is dependent upon the subsurface soil properties;

(2) Angled, horizontal, or directional drilling techniques are often required to install the refrigeration pipes in a manner to isolate the bottom of the containment;

(3) Groundwater flow through the strata can retard and in some cases prevent the formation of the frozen barrier; however, in most applications these effects can

be overcome by lowering the temperature of-the refrigeration medium or reducing the spacing between the adjacent refrigeration pipes;

(4) Groundwater velocities of greater than 5 meters per day generally require adjustments in the design which can include the lowering of the coolant temperature or decreasing the spacing between the adjacent freeze pipes;

(5) The presence of contaminants can influence the freeze point temperature of the strata. Laboratory freeze tests should be conducted on undisturbed contaminated samples to determine the necessary freeze point for the specific site conditions;

(6) Frozen soil permeability tests should be conducted on undisturbed samples of each strata using ethylene glycol as the refrigerant to freeze the sample and the most contaminated groundwater as the permeate. The back pressure on the sample as well as the head pressure on the permeate should be as close to field conditions as possible; and

(7) The water content and grain size analysis of the soil are required to conduct a thermal analysis for the purpose of determining the time for freezing and the spacing between pipes. Typically, the larger grained sands and gravels freeze much quicker than the fine-grained clays and silts.

PERFORMANCE:

There are no data available regarding the performance of freeze walls in an environmental application; however, one installation at an MGP site will be installed and utilized in 1994 as part of a gas holder excavation.

REFERENCES:

Sopko, Joseph A. and G.F. Aluce, Layne Northwest Company, "Ground Freezing for Containment and Remediation", 1993.

IN SITU TREATMENT

AQUEOUS EXTRACTION/FLUSHING

MEDIA:

Contaminated soil, sediment, purifier box wastes, and free-phase hydrocarbons.

TARGET CONTAMINANTS:

VOCs, PAHs,, phenolics, free and weak-acid dissociable cyanide, and heavy metals.

RELEVANT INDUSTRIAL EXPERIENCE:

A field demonstration test of *in situ* flushing was completed at a wood treating site in Minnesota. Lab-scale studies of *in situ* flushing have been completed on contaminated soils from MGP sites and a demonstration of the technology will be conducted at a site in the first quarter of 1994.

DESCRIPTION:

In situ extraction reduces contaminant concentrations in soil by continuously passing an aqueous solution through the zone of contamination. During this process, the contaminants in the soil partition into the aqueous phase and are removed as the aqueous solution is withdrawn from the subsurface. The aqueous solution is then subjected to treatment to reduce the concentrations of the extracted contaminants after which it is usually recycled into the subsurface to minimize the overall water requirements. *In situ* extraction attempts to remove contaminants which are held in the interstices of the soil particles as well as those which are adsorbed to the soil particles. To aid this process, it is often necessary to enhance the solubilization and/or desorption of the contaminants by placing additives into the aqueous solution. Typical additives include surfactants, chelating agents, acids or bases, or organic solvents. The choice of the additive or additives for a particular application is dictated by the type of contaminants, the soil characteristics, and the compatibility of the additive(s) with the subsurface environment and the treatment system that is selected for the recirculated groundwater. For the most part, it is desirable to add only traces of the additives since they may complicate the development of an acceptable water management scheme.

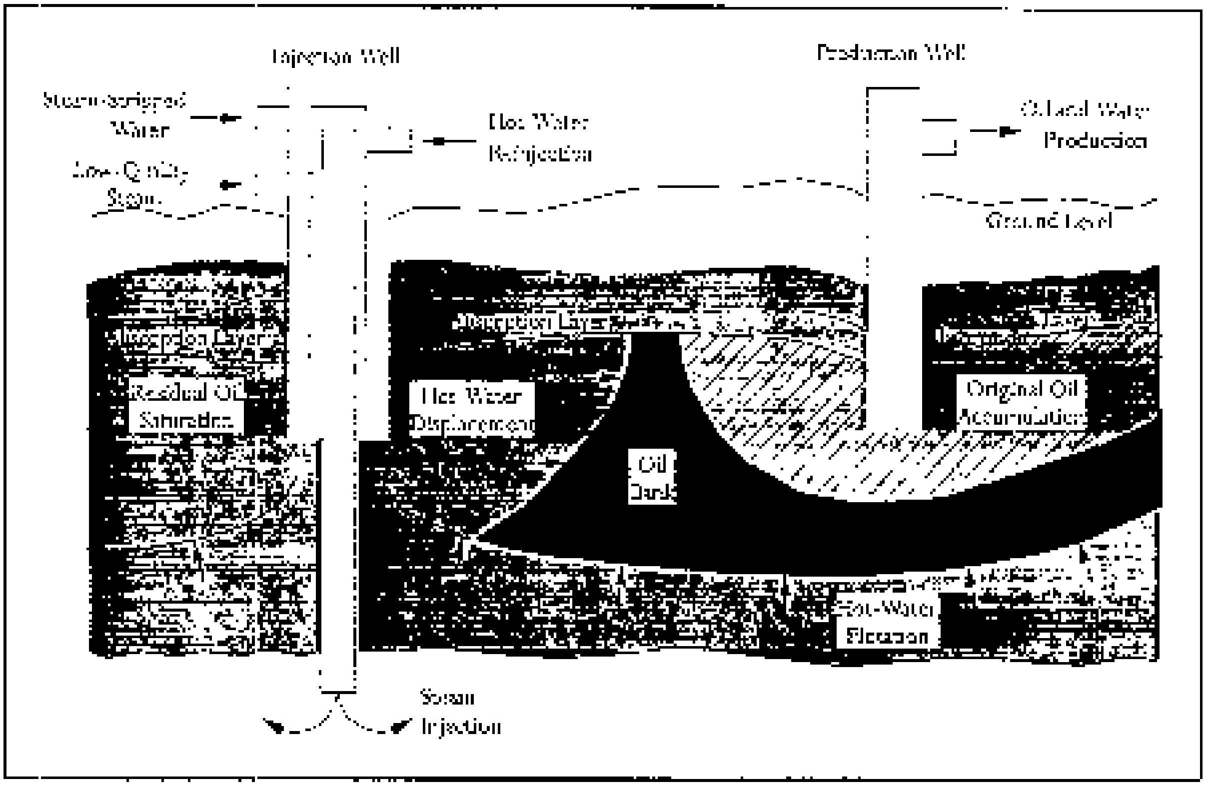


Figure A-25. Process Flowsheet for *In Situ* Steam/Hot Water Flushing (CROW™ Process.)

In situ flushing is similar to *in situ* extraction with the exception that it is usually targeted for the removal of free phase hydrocarbons that are more dense than water or DNAPLs. One possible flushing technique, shown in Figure A-25, involves the use of steam and was derived from the steam flooding techniques that are used for secondary oil recovery and for primary production of heavy oil and tar sands bitumen. The steam is used to heat the DNAPL deposit, decreasing the density and viscosity of the DNAPL to near that of water. With a density and viscosity similar to that of water, the hot steam condensate can dislodge the DNAPL and provide a motive force for its displacement from the subsurface. Typically, the DNAPL and hot condensate are removed from the subsurface via extraction wells. Above ground, the DNAPL and water are separated. Volatile organic compounds are then removed from the water prior to injection into the subsurface. The quantity of water that requires treatment is a function of the amount of steam that is injected into the subsurface and the amount of groundwater that is removed with the DNAPLs. An alternative to steam injection is the injection of a water soluble polymer. The purpose of the polymer is to increase the density and viscosity of the groundwater to that of the DNAPL. Once again, with a similar density and viscosity, the DNAPL and water can be removed from the subsurface using conventional recovery wells.

PERFORMANCE:

Extensive research and development has been conducted to demonstrate the potential of extraction and/or flushing as technologies for the remediation of sites that are contaminated with heavy organics. The research includes field-scale demonstration tests on a site that was contaminated with creosote oil. More recently, there are plans to conduct a similar field-scale demonstration test at an MGP site in Stroudsburg, PA. For the most part, *in situ* flushing will be used prior to the application of *in situ* extraction or *in situ* bioremediation. The flushing is capable of removing the gross contamination that is represented by the free phase hydrocarbons and permits a more effective use of extraction and/or bioremediation for the treatment of the residual concentrations of contaminants that remain in the soil and groundwater system.

REFERENCES:

Luthy, R. G., D. A. Dzombak, C. A. Peters, M. A. Ali, and S. B. Roy, "*In Situ* Solvent Extraction For Remediation of Coal Tar Sites," Draft Final Research Project Report 3072-2, Electric Power Research Institute, Palo Alto, CA, March, 1992.

BIOLOGICAL TREATMENT

MEDIA:

Contaminated soil, sediment, and water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, free/weak-acid dissociable cyanide, ammonia, and conventional pollutants such as TOC, BOD, and COD.

RELEVANT INDUSTRIAL EXPERIENCE:

This technology has been used extensively for the treatment of soil and groundwater contaminated with petroleum products or petroleum-derived hydrocarbons. Fewer applications have occurred in the wood treating industry. Use at MGP sites has been limited to lab-scale investigations and pilot-scale field demonstration tests.

DESCRIPTION:

Subsurface biological treatment is a potentially feasible method for *in situ* treatment of soil, sediment, and groundwater contaminated with 'coal- and petroleum-derived organics and inorganics. In this process, groundwater is withdrawn from the subsurface and is recirculated through a contaminated subsurface zone so as to promote the growth of indigenous microorganisms and the biodegradation of contaminants. Nutrients and electron acceptors (e.g., nitrate or oxygen) are added to the circulating groundwater to stimulate the growth of naturally occurring bacteria which utilize the organics both as an energy source and a food source. Oxygen is usually added in the form of hydrogen peroxide (H_2O_2) and nitrate can be added as sodium nitrate ($NaNO_3$). As such, both aerobic and anaerobic conditions, respectively, can exist. Surfactants can be added to aid in the desorption of chemical contaminants from soil particles into the water phase. The recirculated groundwater is usually introduced into the subsurface using injection wells or a french drain system. Extraction wells or trenches can be used to recover the groundwater downgradient. The extracted groundwater may be further treated above ground and then discharged, or injected back into the ground to increase the flushing of the subsurface contaminants. Such above ground treatment can involve only oil/water separation or it may also include treatment technologies for the treatment of soluble contaminants. Figure A-26 presents a flowsheet for a typical subsurface biological treatment system.

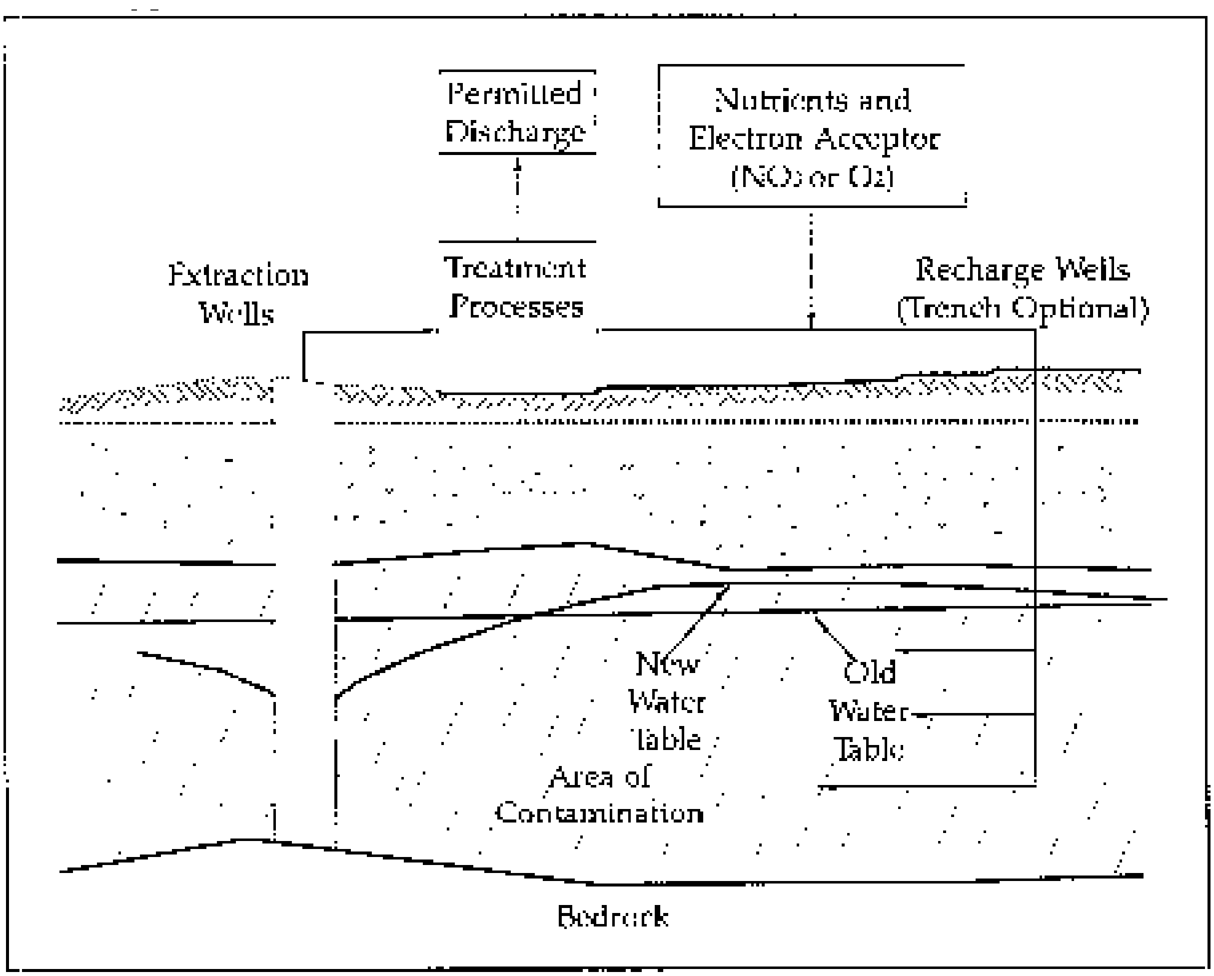


Figure A-26. Process Flowsheet for Subsurface Biological Treatment.

PERFORMANCE:

In situ applications were pioneered in 1972 by Sun Refining to remediate a gasoline spill. Since that time, there have been a number of engineering advancements in nutrient and electron acceptor delivery systems and it is estimated that over 200 *in situ* projects have been implemented. To date, most full-scale applications have focused on restoration of soils and groundwaters contaminated by soluble hydrocarbons from leaky underground storage tanks (e.g., volatile organics). Both lab-scale and full-scale research is being performed on soils and groundwaters contaminated with phenolics (e.g., pentachlorophenol), PAHs, and VOCs. Lab-scale work has demonstrated pentachlorophenol reduction from an initial soil concentration of approximately 13,000 mg/Kg (dry weight) to approximately 1,000 mg/Kg in an eight-week period under denitrifying conditions. For the most part, the most successful applications have been those in which air and nutrients have been injected into the subsurface to enhance the growth of indigenous microorganisms. To date, the addition of other additives have not proven beneficial to the process nor enhanced its effectiveness.

In situ biological treatment has been tested at two MGP sites, one as part of a full-scale site remediation and other as a pilot-scale field test to support a proposed Record of Decision for the site. In both cases, the technology was only marginally effective due to the inability to move reactants throughout the subsurface. This was caused by a heterogeneous subsurface geology in one case and aquifer plugging from chemical precipitates in the other case. Nevertheless, given the appropriate conditions, this approach to biological treatment may play a role in MGP site remediation.

REFERENCES:

Brown, R. A., et. al., "Aquifer Restoration with Enhanced Bioreclamation," *Pollution Engineering,* November, 1985.

Brubaker, G. R., and E. L. Crockett, "*in Situ* Aquifer Remediation Using Enhanced Bioreclamation," Presented at *HAZMAT 86,* Atlantic City, New Jersey, June 2, 1980.

JRB Associates, *In Situ Treatment of Hazardous Waste Contaminated Soils,* U.S. Environmental Protection Agency, Cincinnati, OH, PB86-244746, August, 1986.

CHEMICAL OXIDATION

MEDIA:

Contaminated soil, sediment, and water.

TARGET CONTAMINANTS:

VOCs, PAHs, phenolics, ammonia, free/weak-acid dissociable cyanide and selected metals.

RELEVANT INDUSTRIAL EXPERIENCE:

Limited use of this technology has been reported for hazardous waste sites. One application to an MGP site has been reported for the *in situ* treatment of groundwater.

DESCRIPTION:

In situ chemical oxidation is a potentially viable approach to remediate soil, sediment, and groundwater. A groundwater injection and recovery system is required to provide for the efficient transport of the chemical oxidant through the contaminated zones without either plugging the aquifer or spreading the contamination. Injection wells or french drains can be used to introduce recirculated water that has been dosed with a chemical oxidant into the contaminated zone. Extraction wells or trenches can be used to recover the treated groundwater downgradient from the point of injection. Often, recovered groundwater passes through an aboveground treatment system prior to reinjection. Furthermore, containment barriers may be necessary to provide adequate control of the subsurface migration of the site contaminants.

Potential chemical oxidants include potassium permanganate, hydrogen peroxide, ozone, chlorine and chlorine dioxide. Solutions of these oxidants have viscosities and densities that are similar to water and they are not highly reactive. The *in situ* treatment effectiveness can be greatly hampered by the natural soil organic materials or other oxidizable soil constituents such as reduced iron or manganese. On the other hand, metals that are typically found in soil may enhance the oxidation by serving as catalysts for the oxidation reactions. Lastly, the combination of reduced iron and hydrogen peroxide, otherwise known as Fenton's Reagent, has also been documented as a potential oxidant which can partially oxidize organic contaminants and improve their susceptibility to biodegradation.

PERFORMANCE:

The subsurface injection of hydrogen peroxide has been practiced at one MGP site for the purposes of removing soluble iron from the groundwater. The iron removal was required as part of a state permit for water management at the site. The hydrogen peroxide accomplished .the iron removal by oxidizing the soluble ferrous iron to the insoluble ferric iron. No specific data have been reported regarding the details of the system design or the quantities of hydrogen peroxide which have been required to 'achieve the desired degree of treatment.

REFERENCES:

Gas Research Institute, *Management of Manufactured Gas Plant Sites - Volume IV: Site Restoration,* Chicago, IL, GRI-87/0260.4, October, 1987.

STABILIZATION

MEDIA:

Contaminated soil, sediment, purifier box wastes, and flee-phase hydrocarbons.

TARGET CONTAMINANTS:

PAHs, heavy metals, and all forms of cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

A full-scale remediation of an MGP site was completed in Georgia and demonstration tests have been conducted on an MGP site in Wisconsin.

DESCRIPTION:

Stabilization, is the process by which contaminant mobility in a solid matrix is decreased through physical and/or chemical means. *In situ* stabilization involves the application of the reactants directly to the soil surface or by injecting them into the contaminated subsurface soils. *In situ* stabilization requires the use of specialized injectors and augers that simultaneously inject the stabilizing agent and mix it with the contaminated matrix. This approach to *in situ* treatment can be conducted in both the saturated and unsaturated zones of the subsurface.

As applied to contaminants in groundwater, stabilization involves the processes of adsorption, ion exchange, and precipitation. Adsorption is applicable to both organic compounds and metals and is achieved by injecting absorbants or complexing agents that bind the contaminant into a complex that strongly adsorbs to soil. Ion exchange applies to metals and requires the alteration of the cation exchange capacity of the soil to immobilize cationic metals. Precipitation involves the complexing of metals with chemical reactants that precipitate soluble metals and render them immobile. However, in all of these cases, there is a general concern that the aquifer will become clogged by the products of the physical or chemical reactions that occur in the subsurface. As such, this approach has not been frequently used; rather, the groundwater is usually extracted before it is subjected to this type of treatment.

PERFORMANCE:

A full-scale application of the *in situ* stabilization of contaminated source material and soil has occurred at an MGP site in Columbus, Georgia. The contaminated materials were located primarily in a 15-foot thick zone below the water table and underlying 10 to 20 feet of miscellaneous fill. The maximum contaminants that were present in the soils were 260 mg/Kg of VOCs, 2400 mg/Kg of PAHs, and 5500 mg/Kg of oil and grease. The stabilization equipment included an eight-foot diameter auger that. was advanced using a 100 ton rig capable of developing a torque of 200,000 foot-pounds. Cement additive was introduced as a slurry through the hollow stem auger shaft at controlled rates. The slurry was pumped through exit ports located at the bottom of the auger flights and thoroughly blended with the contaminated soils. A total of 1823 overlapping auger holes were drilled and stabilized, representing a total stabilized volume in excess of 82,000 cubic yards. The duration of the remediation project was twenty weeks. The project was completed in the spring of 1992 and a post-remediation monitoring plan was implemented which included a system of monitoring wells that were installed around the site perimeter. Groundwater samples are collected quarterly and analyzed for VOCs, PAHs, and total cyanide. If no statistically significant concentrations of contaminants are recorded during the initial five years, monitoring will be discontinued. To date, the first two sampling events have yielded no detectable concentrations of VOCs and PAHs; no data was reported for cyanide concentrations.

No data are available from the demonstration tests that were conducted in Wisconsin.

REFERENCES:

Camp, Dresser and McKee, Inc., *Mobile Treatment Technologies for Superfund Wastes,* EPA Report No. 540/2-86/003f, U.S. Environmental Protection Agency, September, 1986.

GeoCon, Inc., *Shallow Soil Mixing: Soil Stabilization: Case Study No. 2, C*-SSM-02-93, 1993.

VAPOR EXTRACTION

MEDIA:

Contaminated soil and vapor.

TARGET CONTAMINANTS:

VOCs, selected PAHs, and free cyanide.

RELEVANT INDUSTRIAL EXPERIENCE:

Applications reported in the wood treating, petroleum refining, petroleum storage, and chemical manufacturing industries. Use at MGP sites limited to lab- or pilot-scale investigations.

DESCRIPTION:

A process flowsheet of a vapor extraction system in the unsaturated zone is shown in Figure A-27. The subsurface vapor is withdrawn through a central borehole by means of a surface blower. The blower creates a partial vacuum in the subsurface which creates a flow of soil gas to the extraction well. The contaminants that are present in the vapor are extracted at the same time. Since the contaminants in the vapor originated in the soil, this process also results in the treatment of the soil. The vacuum at the well may be 6 to 10 inches of water but decreases rapidly with distance from the well. A typical vapor extraction well may supply between 1 to 10 scfm of air per linear foot' of screened pipe and produce a radii of influence in the subsurface of as much as 300 feet under sealed surfaces. For unpaved surfaces, a radius of 50 to 100 feet is more common. If the site is covered by a surface barrier, air inlet holes may be used to enhance air movement through the subsurface.

The contaminated discharge from the vapor extraction system is typically treated by activated carbon adsorption or catalytic oxidation, as necessary, to meet emission standards for the volatile contaminants.

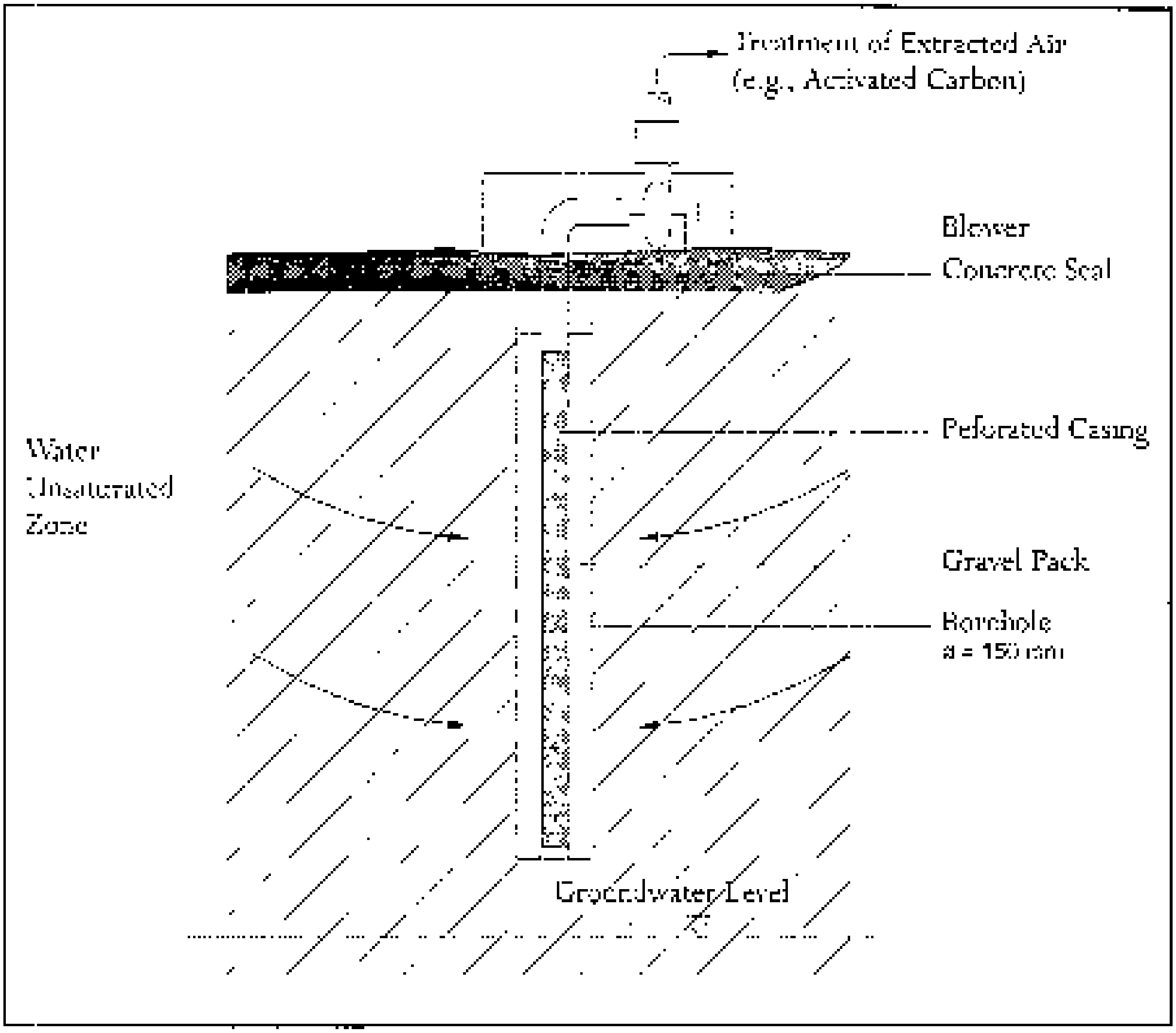


Figure A-27. Process Flowsheet for Vapor Extraction.

PERFORMANCE:

This technology has been demonstrated in lab-, pilot- and full-scale applications. Vapor extraction of soil is very well suited for the removal of VOCs that are present in the air voids of unsaturated soil. As the air containing the contaminants is displaced, the soil-vapor equilibrium concentrations for the contaminant are re-established resulting in the continuous removal of contaminants from the soil as it passes through the subsurface. As vapor extraction proceeds, the contaminant concentrations in the air decrease logarithmically until a residual concentration is achieved. This residual concentration represents a non-equilibrium condition that is governed by the rate of mass transfer of the contaminant from the soil to the vapor phase. At this point, the vapor extraction can be discontinued to permit the soil-vapor equilibrium to be reestablished. When the vapor extraction is continued, the contaminant concentration in the vapor phase has increased and then once again decreases over time. This cycling process is sometimes used to enhance subsurface cleanup in an attempt to reduce the time required for site remediation.

Subsurface site conditions which affect vapor extraction include soil type and porosity, soil permeability, percent moisture and depth to groundwater.

REFERENCES:

U.S. EPA. *Guide for Conducting Treatability Studies Under CERCLA: Soil Vapor Extraction,* Risk Reduction Engineering Laboratory, Cincinnati, Ohio, March 1, 1991.

Harress Geotechnics, Inc. *Investigation and Remediation of Soil and Groundwater Contaminated by Volatile Organic Compounds (VOCs),* Pittsburgh, Pennsylvania, March, 1988.

B

REMEDIATION CASE STUDIES

The remediation case studies that are profiled in this appendix were prepared based upon a phone survey. Only utilities that were known to be involved with site remediation were contacted to complete the survey. Approximately twenty utilities provided information. As such, it is likely that there are other remediation efforts at MGP sites which have been conducted or that are in progress that have not been summarized in this appendix. Furthermore, the information that is provided is only meant to present an overview of the remediation effort and, if possible, to identify an individual who can be contacted for more details or information. Anyone wishing to provide additional case studies for inclusion in the updated editions of this report should contact either Dr. Ishwar Murarka of EPRI (415/855-2150) or Mr. C. Richard Bozek of EEI (202/508-5641).

UTILITY:

Baltimore Gas and Electric

SITE LOCATION:

Baltimore, MD

REMEDIATION ACTIVITY:

Contaminated Water:

Pump and treat system has been designed for groundwater. Treatment system includes gravity separation, dissolved air flotation, fluidized bed biological treatment, filtration, carbon adsorption, and alkaline chlorination. Alkaline chlorination was added to provide treatment for "cyanide amenable to chlorination". The treated water will be discharged to a surface water body.

STATUS/PERFORMANCE:

A three-month pilot-scale study (15 to 20 gpm) was completed and formed the basis for the full-scale system design. The design of an 80 to 100 gpm full-scale system is currently in progress. An NPDES discharge permit application has been filed and approval is pending.

AVAILABILITY OF REPORT:

No report is available although preparation of a technical report has been initiated.

CONTACT:

Herbert Hoffman (410-291-4731)

UTILITY:

Central Illinois Public Service

SITE LOCATION:

Taylorville, IL (Superfund site)

REMEDIATION ACTIVITY:

Source Material:

Approximately 12,000 cubic yards of source material and contaminated soil were excavated and landfilled in a special waste disposal facility.

Contaminated Groundwater:

A groundwater pump and treat system has been designed and will be operational in 1994. The system will treat 200 to 500 gpm using carbon adsorption.

STATUS/PERFORMANCE:

Groundwater remediation will be initiated at the site in *1994.*

AVAILABILITY OF REPORT:

Reports will be available through the U.S. EPA as part of the public record.

CONTACT:

Donald Richardson - (217-525-5575)

UTILITY:

Confidential

SITE LOCATION:

Confidential

REMEDIATION ACTIVITY:

Source Material:

The contents of a subgrade structure were removed. The free phase hydrocarbon or tar (approximately 35,000 gallons), which was a characteristic hazardous waste due to ignitability and the presence of benzene, was separated from the water and was sent to a tar processing facility of Allied Signal in Birmingham, AL. This facility, which has a RCRA Part B Permit, incorporated the tar into its tar production process where it was either recovered or utilized as fuel. Water that was separated from the tar at the facility was biologically treated in an onsite waste water treatment plant.

Contaminated Water:

The contaminated water from the subgrade structure (approximately 48,000 gallons) was transported to an offsite facility where it was subjected to treatment in a carbon adsorption unit prior to final disposal.

STATUS/PERFORMANCE:

The removal of the bottom residues from the subgrade structure has been initiated. This effort has required the deployment of personnel into the tank under confined entry health and safety requirements. The remediation of the contaminated soils that surround the subgrade structure may be addressed using vapor extraction or *in situ* bioventing.

AVAILABILITY OF REPORT:

No reports are available.

CONTACT:

No contact was provided.

UTILITY:

Confidential

SITE LOCATION:

Confidential

REMEDIATION ACTIVITY:

<u>Source Materials and Contaminated Soil</u>:

Approximately 1000 tons of these materials were excavated and stabilized with portland cement and ash. The material, which was a characteristic hazardous waste because of benzene, was disposed of in an offsite hazardous waste landfill.

STATUS/PERFORMANCE:

The remediation effort has not yet been completed.

AVAILABILITY OF REPORT:

No reports are available for this effort.

CONTACT:

No contact provided.

UTILITY:

Confidential

SITE LOCATION:

Confidential

REMEDIATION ACTIVITY:

Contaminated Soil:

Approximately 4400 tons of contaminated soil were excavated and managed in three offsite treatment demonstration tests. Six hundred (600) tons were co-burned in a utility boiler, Fifty (50) tons were processed into hot-mix asphalt, and 3750 tons were processed in a cement kiln. (Soil was fed to the kiln at a raw material to soil ratio of 100:1 to 50:1).

Contaminated Water:

Contaminated water (60,000 gallons) from the site excavation was treated onsite using coagulation/flocculation followed by filtration and carbon adsorption. The treated water was discharged to a Publicly Owned Treatment Works.

STATUS/PERFORMANCE:

Demonstration tests are complete. Hot-mix asphalt was used to pave roads at local power generating facility.

AVAILABILITY OF REPORT:

No report available.

CONTACT:

No contact provided. □

UTILITY:

Georgia Power

SITE LOCATION:

Columbus, GA

REMEDIATION ACTIVITY:

Source Materials and Contaminated Soil:

In situ stabilization was used at this MGP site. The contaminated soils were located primarily in a 15-foot thick zone below the water table and underlying 10 to 20 feet of miscellaneous fill. The maximum contaminants that were present in the soils were 260 mg/Kg of VOCs, 2400 mg/Kg of PAHs, and 5500 mg/Kg of oil and grease. The stabilization equipment included an eight-foot diameter auger that was advanced using a 100 ton rig capable of developing a torque of 200,000 foot-pounds. Cement additive was introduced as a slurry through the hollow stem auger shaft at controlled rates. The slurry was pumped through exit ports located at the bottom of the auger flights and thoroughly blended with the contaminated soils. A total of 1823 overlapping auger holes were drilled and stabilized, representing a total stabilized volume in excess of 82,000 cubic yards. The duration of the remediation project was twenty weeks. The project was completed in the spring of 1992.

STATUS/PERFORMANCE:

Stabilization of the site was just completed within the last year. The short-term effectiveness of this treatment has been given favorable review; however, the long-term effectiveness will be evaluated using a post-remediation monitoring plan. This plan includes a system of monitoring wells that were installed around the site perimeter. Groundwater samples will be collected quarterly from these wells and analyzed for VOCs, PAHs, and total cyanide. If no statistically significant concentrations of contaminants are recorded during the initial five years, monitoring will be discontinued. To date, the first two sampling events have yielded no detectable concentrations of VOCs and PAHs; no data was reported for cyanide concentrations.

AVAILABILITY OF REPORT:

A report is available for this remediation effort and can be obtained from the Georgia Power Company.

CONTACT:

Darayhl Dennis - (404-526-7064)

UTILITY:

IES Industries

SITE LOCATIONS:

Fairfield, IA

Other sites in the State of Iowa

REMEDIATION ACTIVITY:

Source Material and Contaminated Soil:

Approximately 1000 tons of these materials have been excavated from several MGP sites. The excavated material was typically dried onsite through the addition of absorbants. Nonhazardous material was co-burned in a utility cyclone boiler and processed in a cement kiln. Material designated as hazardous was sent to a RCRA incinerator.

Contaminated Groundwater:

Contaminated groundwater was treated using gravity settling and carbon adsorption. The treated water was discharged to a POTW (Publicly Owned Treatment Works).

A pilot-scale field test of *in situ* bioremediation was conducted at the Fairfield site. The approach involved the subsurface addition of nutrients and hydrogen peroxide to stimulate the biological degradation of contaminants. This study was performed concurrently with a laboratory study that was designed to evaluate the feasibility of *in situ* bioremediation at this site. This laboratory effort was supplemented by GRI as part of their ongoing effort to provide a screening protocol for the bioremediation of MGP site soils.

STATUS/PERFORMANCE:

The management of source materials and contaminated soils has been successful. The groundwater pump and treat system has been on-line since 1990 and has also performed well. However, the *in situ* bioremediation of the soils and groundwater was not as successful due to the heterogeneity and low permeabilities of the subsurface geology at the site.

AVAILABILITY OF REPORT:

A report of the laboratory study that was in support of the *in situ* bioremediation field study has been published and may be available through the utility. The title of the report is "*In Situ* Bioremediation of PAH Contamination at a Former Manufactured Gas Plant Site." In addition, the results of the supplemental lab study that was conducted by GRI will be completed in the first quarter of 1994.

CONTACT:

Dean Hargens - (319-398-4658)

UTILITY:

Jersey Central Power and Light

SITE LOCATION:

Several MGP sites in the State of New Jersey

REMEDIATION ACTIVITY:

Source Materials and Contaminated Soil:

These materials have been excavated using standard techniques after which asphalt caps have been installed. Materials classified as hazardous are transported to hazardous waste landfills or incinerators. Nonhazardous materials have been recycled for use in the manufacture of cement or hot-mix asphalt. In the future, it is anticipated that onsite thermal desorption may be used as an alternative treatment option for the more heavily contaminated materials.

Contaminated Groundwater:

Contaminated groundwater is managed using pump and treat systems. A research effort is currently underway with EPRI to define the optimal treatment strategy for these groundwaters. Efforts to date have included lab-scale treatability studies to investigate air strippers and carbon adsorption.

STATUS/PERFORMANCE:

Current remediation efforts have been technically successful. Pilot-scale tests to optimize the treatment of groundwater will be initiated in 1994 based on the lab-scale results.

AVAILABILITY OF REPORT:

No reports are currently available although EPRI will report on the research efforts related to treatment of the groundwater.

CONTACT:

Colin Sweeney - (201-455-8784)

UTILITY:

Midwest Gas Company

SITE LOCATIONS:

Dubuque, IA (Peoples Natural Gas - Superfund site)

Dubuque, IA (Key City Gas - State site)

Waterloo, IA

REMEDIATION ACTIVITY:

Contaminated Soil:

Contaminated soil (8000 to 10000 tons) was excavated at both Dubuque, IA, sites and were co-burned in a utility boiler. The soil was fed to the boiler after it was mixed with the feed coal. (Feed mixture consisted of 4 to 6 weight percent of soil in coal).

Field-scale demonstration tests of prepared-bed land treatment have also been completed using the excavated soil from the Superfund site. The tests examined the treatment of approximately 25 cubic yards of contaminated soil, with and without the addition of Fenton's Reagent to the treatment system. These tests were conducted in 1991 and 1992. In 1993, the same pilot-scale treatment unit was used to investigate the prepared-bed land treatment of soils from the MGP site located in Waterloo, IA.

Contaminated Water:

Groundwater from the Superfund site is recovered at a rate of 30 gpm and is processed through a gravity separator and an air stripper. The treated water is discharged to a POTW (Publicly Owned Treatment Works).

Contaminated groundwater at the state site also contains gasoline contaminants. A pump and treat system has been designed to treat 50 to 70 gpm and consists of an oil/water separator, air stripper, and carbon adsorption system. The treated water will be discharged to a POTW (Publicly Owned Treatment Works).

STATUS/PERFORMANCE:

Groundwater pumping is occurring at the Superfund site. In addition, a pilot-scale investigation of *in situ* bioremediation is planned for the site. The design of the groundwater treatment system for the state site is in progress.

The prepared-bed land treatment demonstration tests have been completed for the soils from the Superfund site in Dubuque, IA, but are still in progress using the soils from the site in Waterloo, IA.

AVAILABILITY OF REPORT:

No data have been reported for the groundwater treatment or co-burn tests at the power generating stations. Extensive reporting of the field-scale demonstration tests of the prepared-bed land treatment of the soils from the Superfund site in Dubuque, IA, has been done by the Gas Research Institute and the Institute of Gas Technology.

CONTACT:

G.L. (Sam) Nelson - (712/277-7930)

UTILITY:

New York State Electric and Gas

SITE LOCATION:

Several MGP sites throughout the State of New York

REMEDIATION ACTIVITY:

Source Material:

A low permeability slurry wall was placed around a former tar lagoon to completely isolate the free phase hydrocarbons that were present. The slurry wall was keyed into a subsurface soil strata of low permeability. Other contaminated solids were excavated at the site and were placed in this containment cell. The containment cell was then capped.

Contaminated Soils:

A demonstration test was completed to test the co-burning of contaminated soils in a stoker boiler. The test was conducted under a Research Development and Demonstration Permit with the intent of receiving an operating permit for the facility to routinely process contaminated soils from MGP sites. Approximately 9000 tons of soil were treated and the test results were submitted to the state regulatory agency for their review. In addition, an environmental impact statement for this boiler application was prepared and has been released for public comment. (Note: Contaminated soil that was used in the test burn was received from another utility.)

Contaminated Groundwater:

As part of the installation of the slurry wall around the former tar lagoon, a groundwater pump and treat system was also installed. The groundwater is treated using potassium permanganate to oxidize and remove dissolved iron and carbon adsorption for the removal of organic contaminants. Approximately 10,000 gallons of groundwater are treated every week and the treated water is discharged to a surface water body through a state discharge permit.

In situ groundwater treatment was also investigated in conjunction with the slurry wall. The *in situ* approach involved the recovery of the groundwater, surface treatment to enhance biological activity, and injection into the subsurface through an upgradient infiltration gallery. The investigation revealed that the fouling of the infiltration galleries precluded the effective use of this treatment strategy.

A pilot-scale field test of air sparging was also initiated at an MGP site. The test is designed to examine the use of the direct injection of air into the subsurface aquifer as an *in situ* approach for the remediation of contaminated groundwater.

A field demonstration test of the direct discharge of contaminated groundwater to a POTW was completed. The two-month study involved an indepth analysis of the POTW operation both before and after the discharge of the groundwater. The analyses consisted of contaminant material balances over the entire system.

STATUS/PERFORMANCE:

The effectiveness of the slurry wall has not been formally evaluated since its installation; however, the groundwater pump and treat system, consisting of permanganate addition and carbon adsorption, continues to operate and meet the discharge permit requirements. No data are available for the air sparging field test or the POTW discharge study and the co-burn test results and EIS are currently undergoing review by the public and the regulatory agencies.

AVAILABILITY OF REPORT:

No public reports are available although all of the regulatory documents related to the discharge of the treated groundwater, the co-burn test monitoring, and the co-burning EIS are accessible through the New York Department of Environmental Conservation.

CONTACT:

Thomas O'Meara - (607-762-4036) □

UTILITY:

Niagara Mohawk Power Corporation

SITE LOCATION:

South Glens Falls, NY

REMEDIATION ACTIVITY:

Contaminated Soils:

Approximately 15000 tons of contaminated soil were excavated and transported by truck to offsite treatment facilities. The majority of the hydrocarbon-contaminated soil was sent to Giant Resources Recovery in South Carolina where it was processed in a thermal desorption unit. The treated soil was used as a clean aggregate for the production of hot-mix asphalt. A small quantity (approximately 40 tons) of the excavated material was sent to Heartland Cement in Heartland, Kansas, where it was processed in a cement kiln.

Contaminated Water:

Excavation and surface runoff water was collected and trucked directly, without pretreatment, to the POTW (Publicly Owned Treatment Works). Approximately 740,000 gallons of water were managed at the site.

STATUS/PERFORMANCE:

The source and soil remediation efforts are complete; however, groundwater monitoring has been occurring for nearly two years and will be continued by NMPC and EPRI for the next eight years. This monitoring program is part of a long-term research effort to document the role of intrinsic biological and chemical processes in the subsurface remediation of groundwater.

AVAILABILITY OF REPORT:

Several reports of the remediation efforts at this site have been produced by EPRI and NMPC. An overview of the work entitled "Organic Substances in the Subsurface: Delineation, Migration, and Remediation" is available from EPRI or NMPC.

CONTACT:

Michael Sherman - (315-428-6624)

UTILITY:

Niagara Mohawk Power Corporation (NMPC)

SITE LOCATION:

Utica, NY

REMEDIATION ACTIVITY:

One of the more significant industrial research thrusts related to MGP site remediation represents the combined efforts of the Niagara Mohawk Power Corporation (NMPC) of Syracuse, New York, the national utility trade organizations of GRI and EPRI, the utility trade organizations of New York State (i.e., the Empire State Energy and Electric Research Corporation and the New York Gas Group) and the U.S. Environmental Protection Agency. This research program has targeted the field demonstration of many of the remediation technologies that have been previously investigated in either laboratory- or pilot-scale apparatus. The objective of the technology field demonstration project is to generate performance, economic, and reliability data for these technologies to permit an evaluation of their full-scale applications at MGP sites.

The planning, or Phase I of the project, was completed at the end of 1992. The field demonstration tests were initiated in late 1992 and have extended through 1993. These tests have included a materials removal and handling demonstration test which was followed by the disposition of the excavated and processed materials in a combination of manufacturing facilities that produce hot-mix asphalt, light aggregate, cement, and bricks. This demonstration test focused on the subsurface portion of a "pit" relief holder since these structures are very common at MGP sites and they typically contain a wide variety of debris and contaminated media that require a full complement of material processing steps. The offsite transport of the excavated materials using rail transport was also investigated as part of the demonstration test. The onsite production of cold-mix asphalt from tar-contaminated soils has also been completed and the product is now undergoing laboratory tests to certify the acceptability of its environmental and structural characteristics. Lastly, a thermal desorption demonstration test was completed in 1993 that examined the treatment of soils and sediments contaminated with a full-range of coal carbonization and carbureted water gas tars.

STATUS/PERFORMANCE:

The test plans for 1994 include an investigation of *in situ* stabilization for source control, *in situ* biological treatment of harbor sediments, and the co-burning of contaminated soil in a utility boiler. Additional materials excavation and handling procedures will also be investigated under sprung structures, primarily as a means of odor control, and a field test program will be executed to test the structural and environmental properties of the cold-mix asphalt that was produced from the contaminated site soil.

AVAILABILITY OF REPORT:

A report of the Phase I project activities has been prepared and is available from NMPC. Phase II project reports will be prepared for each demonstration test. The production of these reports will be funded by NMPC with co-funding support from EPRI. The first of these Phase II reports will be available in the first quarter of 1994.

In addition to the research reports, annual project briefings are planned and will be funded by NMPC.

CONTACT:

Edward F. Neuhauser (315-428-3355)

UTILITY:

Non-Utility

SITE LOCATIONS:

Tacoma, WA

Seattle, WA

REMEDIATION ACTIVITY:

Source Material and Contaminated Solids:

Approximately 40,000 cubic yards of materials was excavated in the mid-1980's from an MGP site in Tacoma, WA. The material was stabilized with kiln dust and landfilled in an offsite hazardous waste landfill.

An MGP site in Seattle was transformed into a park which is known as "Gas Works Park". The site was prepared by installing a soil cover over the entire surface and incorporating the remaining gas production equipment into the park facilities. Later, the gas production equipment was encircled with a fence as an institutional control to prevent direct contact with it.

Contaminated Water:

Contaminants are present in the groundwater beneath Gas Works Park. Consideration has been given to using *in situ* approach for its remediation.

STATUS/PERFORMANCE:

The park is open to the public and no action is immediately planned for the remediation of the groundwater.

AVAILABILITY OF REPORT:

No report is available.

CONTACT:

No contact provided.

UTILITY:

Pennsylvania Power and Light

SITE LOCATIONS:

Lancaster County, PA

Stroudsburg, PA (Superfund site)

Other MGP sites located in Pennsylvania.

REMEDIATION ACTIVITY:

Source Material:

Free phase hydrocarbon was removed from the subsurface at the Superfund site and used as fuel at an industrial boiler. At this same site, a slurry wall was installed as a barrier to isolate the source areas that contained free phase hydrocarbons. Lastly, a field-scale demonstration of enhanced recovery of free phase hydrocarbons will be executed in 1994. This test will examine the application of the CROW™ process which is a hydrocarbon recovery technology that was adapted from the petroleum exploration and production industry. The field demonstration test will be co-funded by the U.S. EPA through their Superfund Innovative Technology Evaluation (SITE) Program.

Recovery of free phase hydrocarbon from the subgrade gas holder tanks that are located in Lancaster County will be accomplished using the CROW™ process. This effort will be completed in 1994 and will be conducted as a tailored collaboration program with EPRI.

Contaminated Soil:

Approximately 1000 cubic yards of contaminated soils have been excavated from other MGP sites, stabilized with kiln dust or lime, and landfilled at offsite disposal facilities. One site was capped following the excavation of surface soils.

Contaminated Water:

The contaminated water that is produced during the recovery of the free phase hydrocarbon at the Superfund site will be treated using gravity separation followed by fluidized bed biological treatment. An NPDES permit has been received for the discharge of the treated water to a surface water body. As part of this permit, it was agreed that the treated effluent could be directly discharged without prior storage and characterization provided that it was processed though a carbon adsorption unit. The design flowrate for the system is 45 gpm. Co-funding for the installation and testing of this produced water treatment system has been provided by GRI.

STATUS/PERFORMANCE:

The limited excavation activities were conducted as interim remedial measures. The effort to recover free phase hydrocarbon and to treat the produced water at the Superfund site is part of a Record of Decision for the site. All designs for this remediation have been approved and it will be implemented during the first quarter of 1994. The recovery of the free phase hydrocarbon from the subgrade gas holder tanks in Lancaster County is planned for the first half of 1994.

AVAILABILITY OF REPORT:

Design reports for the remediation efforts at the Superfund site are available through the U.S. EPA Region III as part of the public record. Reports of the demonstration test results will be developed by PP&L, the U.S. EPA, and GRI following its completion.

CONTACT:

James Villaume - (215-774-5094).

UTILITY:

Public Service Electric and Gas

SITE LOCATION:

New Jersey

REMEDIATION ACTIVITY:

Source Material and Contaminated Soil:

The remediation project consists of two phases. The first phase involves remediation of approximately 16,000 tons of relatively high concentration tar waste from two subgrade gas holder tanks. In the second phase, an additional 100,000 tons of lower concentration waste in the unsaturated zone surrounding the tanks will be remediated. The excavation of the gas holder tanks will be completed using a soil freeze wall to control groundwater infiltration. The excavated materials from both phases will be treated onsite in a thermal desorption system consisting of an electrically heated auger that volatilizes the contaminants after which they are condensed from the overhead gas and then recycled as liquid hydrocarbons.

STATUS/PERFORMANCE:

The first phase remediation commenced in May of 1994 and is scheduled for completion at the end of 1994. The second phase is scheduled for completion in 1996.

AVAILABILITY OF REPORT:

No report available at this time.

CONTACT:

Joseph E. Rosina - (201-430-5259)

UTILITY:

Union Electric

SITE LOCATION:

Confidential

REMEDIATION ACTIVITY:

<u>Contaminated Soil</u>:

Two-thirds of this MGP site will be remediated by excavating source materials and contaminated soils. The remainder of the site, which houses a building and parking lot, will be isolated from the areas of excavation using steel sheet piles.

The excavation of approximately 12000 cubic yards of material is planned for the winter of 1993/1994. It is anticipated that 1000 cubic yards will be classified as a characteristic hazardous waste (due to benzene) and will be landfilled in a hazardous waste disposal facility. An additional 5000 to 7000 cubic yards of the excavated material will be landfilled as a non-hazardous waste. The remaining material (4000 to 6000 cubic yards), which is anticipated to be free of contamination, will be used as backfill to reclaim the site.

In the event that free phase hydrocarbon is encountered during the excavation, thermal destruction options will be evaluated.

STATUS/PERFORMANCE:

The remediation effort will be conducted during the winter of 1993/1994 under an Administrative Order from EPA Region VII.

AVAILABILITY OF REPORT:

Final reporting of the remediation activities will be in the public domain through the U.S. EPA.

CONTACT:

David Pluhar - (314-554-2340)

UTILITY:

Washington Natural Gas

SITE LOCATION:

Tacoma, WA (Superfund Site)

REMEDIATION ACTIVITY:

Source Material:

Excavation of free phase hydrocarbons is occurring at this site. The hydrocarbons are being stabilized with cement and are being disposed of in an offsite hazardous waste landfill.

STATUS/PERFORMANCE:

Site remediation is in progress.

AVAILABILITY OF REPORT:

No report is available although information will be accessible in the public domain through the U.S. EPA.

CONTACT:

No contact provided.

UTILITY:

Yankee Gas

SITE LOCATION:

Confidential

REMEDIATION ACTIVITY:

Contaminated Soils:

Approximately 6000 cubic yards of contaminated soil were excavated and transported to offsite treatment facilities which included the manufacture of brick and the production of hot-mix asphalt.

Co-burning of contaminated soil in a utility boiler is also being considered as part of future remediation efforts.

STATUS/PERFORMANCE:

The fine grain texture of the soil and the high water table made the excavation of the soils very difficult. The offsite treatment investigations indicated that both brick manufacture and asphalt production are viable recycle options for contaminated soils from MGP sites.

AVAILABILITY OF REPORT:

No report is available at this time.

CONTACT:

Ellen Quinn - (203-639-4000)