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CHARACTERIZATION AND UTILIZATION OF MUNICIPAL AND UTILITY SLUDGES AND ASHES

Volume I. Summary

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Volume I

Summary

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and and to recycle valuable resources.

Presented here is a series of studies describing the nature and disposal practices for municipal and utility sludges and ashes. The study was primarily concerned with the sludges emanating from municipal wastewater, and water treatment plants, coal ash from power stations, and grate residue from municipal solid waste incinerators. Each of these subject areas is presented as a separate report. Volume I presents a summary of the results and conclusions developed for each of the subject areas.

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ABSTRACT

The nature and disposal practices for municipal and utility sludges and ashes were studied. The study was primarily concerned with the sludges from municipal waste water, and water treatment plants, coal ash from power stations and grate residue from municipal incinerators. Each of these subject areas is presented in a separate report. Volume I of this series presents the summary for the results and conclusions developed for each of the subject areas.

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INTRODUCTION

Under EPA Grant R-800432 a comprehensive evaluation of disposal and utilization practices for municipal and utility sludges and ashes was performed. This study was primarily concerned with the sludges from municipal waste water and water treatment plants, coal ash from power stations, and grate residue from municipal incinerators. The nature and amounts of these wastes were established and the current disposal and/or reuse practices were examined. To facilitate the presentation of this work the subject matter was divided into three major sections: Municipal Sludges; Utility Coal Ash; and Incinerator Residue. The reports from the studies conducted in each of these subject areas are presented in separate volumes. In this first volume, a summary of the results and conclusions developed for each of the study areas is presented.

The primary objective of a wastewater treatment plant is to prevent pollution of streams, lakes, and ground water supplies, by removing the solid pollutants from the wastewater. The solids removed are in the form of a liquid slurry, called sludge. Sludges are concentrated pollutants. They must be disposed of in a manner that assures public health and environmental safety. Furthermore, disposal methods applied must account for recycling of the organic and useful material of the sludge back to nature; also, the disposal method should be economically feasible.

Sludge handling, treatment and disposal requires many steps, including: concentration, stabilization, conditioning, dewatering and drying, transporting, and solids reduction.

Concentration processes are applied primarily to increase the solids content of the sludge, thus reducing its volume significantly. Sludge concentration might be desirable when: (1) liquid sludge is applied to farmland; (2) sludge is disposed of in the sea (barging); and (3) when savings of chemicals, heat energy, and auxillary fuel in the subsequent steps are questions of concern. Methods used for sludge concentration or thickening include: (1) gravity thickening; (2) dissolved air-flotation; and (3) centrifugation. Gravity thickening is the most widely used, simplest and least expensive sludge concentration method. This process is basically the same as sedimentation settling, but relatively slow in action. The degree of sludge concentration obtained and the efficiency of thickener operation depends on such factors as: (1) initial solids concentration and temperature of the sludge in the thickener; (2) type of sludge and volatile content; and (3) addition of chemicals and inert weighing agents. Typical concentrations that can be obtained for various types of sludges are: 8% for primary, or trickling filter sludges; 5% for modified aeration; and 3% for activated sludge. Flotation thickening of sludge is becoming increasingly popular. The basic principle in flotation thickening is to attach minute air bubbles to the suspended solids of the sludge. This reduces the specific gravity of the solid particles below that of water and causes the solids to separate from the liquid phase while moving in an upward direction.

Four methods of flotation thickening that are used in wastewater treatment plants include: (1) dispersed air flotation; (2) dissolved air pressure flotation; (3) dissolved air vacuum flotation; and (4) biological flotation. Among the above four methods, dissolved-air flotation, and biological flotation have received wide use because of the higher solids concentration obtained. The major variables influencing flotation thickening include: (1) pressure; (2) recycle ratio; (3) feed solids concentration; (4) detention period; (5) air to solid ratio; (6) type and quality of sludge; (7) solids and hydraulic loading rates; and (8) use of chemical aids. Flotation thickeners are used primarily in conjunction with waste activated sludge. Typical concentration obtained from combined primary and activated sludge is 6%. For activated sludge alone, the concentration is 4%; and when chemical aids are employed, 6%. Centrifugation of sludge for thickening and dewatering purposes has long been practiced in wastewater treatment plants. Typical concentration obtained is 7%. Higher concentration is possible using chemical aids.

Raw sludge contains a substantial amount of organic material. Sludges provide food for microorganisms which grow in and upon them. These microorganisms are mostly of fecal origin and many of them are pathogenic, which may be definite health hazards. Therefore, decomposition of the organic material, or sludge stabilization seems an obvious necessity. Methods applied for stabilization of wastewater sludges include: (1) anaerobic digestion; (2) aerobic digestion; (3) composting; (4) lagooning; (5) heat treatment; and (6) chemical stabilization.

Anaerobic digestion of sludge involves decomposition of organic material in the absence of free oxygen. Digestion occurs in two separate stages, called liquefaction and gasification stages. The end product of the first stage is utilized in the second stage as fast as it is produced. Responsibilities of the group of microorganisms (acid forming bacteria) in the first stage are the hydrolysis and fermentation of the complex organic compounds to simpler organic acids. A responsibility of the group of microorganisms (methane forming bacteria) in the second stage is to convert the organic acids to methane gas and CO_2. Anaerobic sludge digestion is the oldest method of stabilization, and it will continue to be used particularly at small sewage treatment plants and in large coastal cities. Factors effecting digestion of wastewater in sludges include: sludge type and volatile content; digester temperature; digestion detention period; feed sludge concentration; degree of digester mixing; digester loading rates; and presence of toxic materials. Three types of anaerobic digesters being used in wastewater treatment plants are: (1) conventional digester, (2) high-rate digesters, and (3) anaerobic contact process.

Aerobic digestion is a biological process during which gross oxidation is completed in two stages: (1) direct oxidation of any biodegradable matter by biologically active masses of organisms, and (2) oxidation of microbial cellular material by endogenous respiration. Aerobic digestion has been used extensively in treating waste activated sludge. Factors effecting design and operation of this process include: rate of sludge oxidation; sludge temperature; oxygen requirements of the system; sludge loading rates; sludge age; sludge solids characteristics; and characteristics of the residue and supernatant liquid. In aerobic digestion volatile solids reduction of up to 50% can be obtained. Rate of reduction is very high in the initial 10-15 days, whereas after 15 days the rate of reduction slows down drastically.

Composting of sludge can be defined as the decomposition of organic waste by aerobic, thermophilic organisms to produce a stable humus-like material. The compost produced can be used as a soil conditioner or fertilizer depending on its nutrient content. Composting methods used include: (1) indoor (mechanical), and (2) outdoor (windows and bins) processes. In the mechanical composting process there are three phases. These are: (1) dewatering of the sludge, (2) composting, and (3) final curing. The factors which affect the composting process include: mixing moisture content; percent of recycled compost; aeration; and temperature and pH. Volume reduction of about 70% with solids reduction of 30% can be obtained. The heat generated (140 ± 5°F) is sufficient to destroy most of the pathogenic bacteria. Composting of wastewater sludge, mixed with refuse, has been found to be more advantageous than composting of either sludge or refuse alone.

Sludge lagoons have been used for sludge stabilization purposes quite frequently, particularly in small plants. They are relatively inexpensive and very simple to operate. Where a lagoon is used for digestion of raw sludge, odor, and insect breeding may be problems. Design parameters commonly used are: land area, climate, subsoil permeability, lagoon depth, sludge loading rate, sludge characteristics and types.

Heat treatment of the wastewater sludge has increasingly gained popularity in recent years. When sludge is heated at high temperatures under pressure, the gel-like structure of the sludge is destroyed and the bound water is liberated. The resulting product is sterilized, deodorized and readily dewaterable. Major processes used include: (1) Zimpro process, (2) Porteous process, and (3) Farrer system.

Application of the heat treatment processes, particularly the Zimpro process (also called wet oxidation), in the treatment of wastewater sludge, is growing rapidly. Operation of these processes includes the following steps: (1) sludge is ground up and pressurized to the selecting operating pressure; (2) sludge is pre-heated by passing it through a heat exchanger; (3) the pre-heated sludge (in the case of wet oxidation, mixture of the sludge and air) is fed into the reactor, where sludge is further heated to about 300 to 400°F for a period of 30 to 60 minutes; (4) the heat conditioned sludge is cooled by heat exchange with the incoming sludge; (5) gases are separated and released through a catalytic after burner or similar devices; and (6) stabilized sludge is concentrated and dewatered to about 40 to 50% solids content without use of chemicals. It has been observed that heat treatment destroys most of the pathogens. The major difference between the Zimpro process and the other two is that the Zimpro process air is introduced into the reactor, and it is not in the Porteous or Farrer systems.

Chemicals have also been used to stabilize the sludge produced from wastewater treatment processes. The two types of chemicals that are very common are chlorine and lime. Both chemicals have been found to be very effective in microbial destruction.

Other methods used for sludge stabilization include solvent extraction, and electrical treatment. Though these methods are very effective and technically promising, they are not economically feasible and many operational problems are associated with them.

Sludge is conditioned principally to improve its dewatering characteristics. Various methods of sludge conditioning that are currently being practiced include: (1) elutriation, (2) chemical conditioning, (3) freezing, and (4) addition of flocculating agents and filter aids, such as fly ash, diatomaceous earth, etc. The sludge moisture content can be reduced to about 70% by means of proper conditioning, followed by a dewatering process.

Elutriation is a washing operation which removes sludge constituents that interfere with sludge thickening and dewatering processes. As the elutriation comes in contact with the sludge particles, dispersants such as carbonates and phosphates are extracted from the sludge as well as non-settleable fine particles, the products of decomposition, and the toxic materials. The elutriation operation can be performed as a batch or continuous process. It could be single stage with single contact between the solids and the liquid, or it could be multistage contact in one or more stages or multistage counter current contact.

Use of chemicals to condition sludge results in coagulation of the solids and the release of the absorbed water from the solid particles. The most common types of chemicals used in conditioning of wastewater sludge include: ferric chloride (either alone or combined with lime); a combination of ferric chloride and alum; or lime alone. Ferric chloride is used in plants dewatering activated sludge, where ferric chloride and lime are used in plants dewatering raw and/or digested sludge. The chemical dosage required for a given sludge is determined in the laboratory. Polyelectrolytes have gained much popularity in recent years as a sludge conditioner. Dewaterability of the sludge and solids content of the filter cake solids captured during the elutriation have significantly been improved in sludge which was conditioned with polymers. Dosage rates of polymers as compared with other chemicals are significantly lower, on the order of 1/50 to 1/100 times of other chemicals.

Freezing has also been applied to sludge conditioning. The conditioning effect produced by freezing is believed to result from dehydration, and the pressure exerted on the sludge particles by the ice structure. A significant increase in solids content and dewaterability of the sludge is attained by slow freezing and thawing, provided that the freezing cycle is complete. Freezing is generally used in cold climates, however, it can be applied in mild climates if the sludge is applied in thin layers 0.5 to 1.0 inch thick.

Fly ash and other filter aids such as diatomaceous earth, sawdust, newsprints, etc., have also been used for sludge conditioning. These materials together with the solid phases of the sludge form a porous, permeable and rigid lattice structure which filters particulates but allows passage of liquid. The amount of fly ash required to improve filterability of activated sludge ranges from 500 to 700% of the initial solids content of the sludge; whereas, for digested sludge it ranges from 100 to 150%.

Sludge dewatering is generally applied to serve such purposes as: reducing the volume of the sludge; reducing the moisture content of the sludge, thus, reducing the fuel costs when sludge is dried or incinerated; and increasing the solids content so that the sludge is easily handled and disposed of. The methods commonly used for sludge dewatering include: (1) sand bed drying;

(2) centrifugation; (3) vacuum filtration; (4) filter press; (5) heat drying; and (6) vibration.

Drying of the sludge on open or covered sand beds is the most common dewatering method presently in use. Open sand bed dewatering is probably the least expensive method of all. It has been used extensively in small (<10,000 pop.) communities. Variables effecting dewatering rates include: (1) climate and atmospheric variations; (2) sludge depth applications; (3) sludge moisture content; (4) origin and type of the sludge; (5) sludge age; (6) drying beds construction; and (7) presence or absence of coagulants. In general, drainage is the predominant dewatering mechanism during the first 2 to 3 days after the application of the sludge, during which, 60 to 85% of the sludge moisture loss occurs. After 2 to 3 days, evaporation becomes the major factor and its rate depends solely on the climatic conditions. The optimum sludge application depth is about 9 inches.

Centrifuges have also been used for municipal sludge dewatering purposes. The three major types of centrifuge used are: (1) basket-design centrifuges; (2) disk-design centrifuge; and (3) solid bowl conveyor centrifuge. The solid bowl conveyor centrifuge has been the most effective of all. Parameters that effect the efficiency of the unit include machine variables, such as bowl design, bowl speed, pool volume, and conveyor speed, and pitch; and process variables, such as feed rate, solid characteristics, feed consistency, temperature, and chemical aids. Total solids of the cake range from 18 to 35%, and the solids recovery varies from 50 to 90% without use of chemicals, and 90 to 98% when chemicals are used.

Vacuum filters are the most common type of mechanical dewatering facilities used today, particularly when incineration is used for final disposal. Various types of vacuum filters used include: (1) drum-type filters; (2) string-discharge filters; (3) belt-type filters; and (4) coil-type filters. Factors effecting dewaterability of the sludge include: (1) sludge solids content; (2) sludge age and temperature; (3) sludge and filtrate viscosity; (4) sludge compressibility;

and (5) the nature of the sludge solids. Chemicals are frequently used for conditioning the sludge. Cake solids contents for various types of sludges range from 15 to 35%.

Filter presses and plug presses have also been used for sludge dewatering purposes. However, their use is very limited in the U.S. because of the high cost of manual labor and maintenance of the system.

Wastewater sludge has been heat dried particularly in conjunction with production of fertilizer or soil conditioner, in which sludge is generally dewatered to a 10% moisture content, utilizing heat dry facilities. Heat drying permits the end products to grind well, reduces sludge weight and odor, destroys pathogens and most important of all provides an ultimate means of disposal by recycling the organic material back into the land. The various types of equipment used for sludge drying include: (1) flash drying system; (2) multiple hearth dryer; (3) rotary kiln dryer; and (4) atomized spray dryer. The most common types are the flash drying and multiple hearth systems. Because of the high costs involved in sludge drying, sludge is generally dewatered by mechanical means prior to drying. The sludge drying temperature commonly used is about 700^{o}F.

Common methods for conveying the resulting liquid or dried sludge from the wastewater treatment plant to a final disposal site include: (1) barging transport; (2) pipeline transport; (3) truck transport; and (4) railroad transport. Barging is generally utilized in coastal cities. Approximately 4.5 million tons (on a wet basis) of wastewater sludge was barged to the sea in 1968. Liquid treated sludge is generally thickened to about 4 to 10% solids content prior to barging. Pipeline transporting of sludge is very common. Its uses include: transport to farmland, to land for land reclamation purposes, to disposal site at sea, and others. Truck transporting of liquid and dried sludge from the plant to the final disposal site is a very common method particularly in smaller treatment plants.

Sludge is generally incinerated for two main reasons: (1) volume reduction, and (2) solids reduction and sterilization. Methods used for sludge incineration are the same as those mentioned for sludge drying purposes with some process modifications. Incineration temperature ranges from 1350 to 1600°F. Sludge is generally dewatered to about 70% moisture content prior to incineration. Sludge combustion is effected by a number of factors, including sludge calorific value, sludge volatile content, and sludge inert content. A typical calorific content of the sludge is about 10,000 Btu/lb of volatile solids. A complete incineration process involves two steps: (1) drying, and (2) combustion. The first step requires auxilliary fuel, whereas the second step could be an endogenous process, depending on the volatile content of the sludge and deodorizing requirements. Sludge incineration has become very common, particularly in large cities, despite the high costs involved. The major types used are multiple hearth and flash drying units. The principal end products of incineration are gases (CO_2, SO_2, NO_x), and inert ashes and residues. It appears that incineration of the sludge involves some degree of hazardous environmental and health effects; however, sufficient data are not available to establish these potential hazardous effects.

Pyrolysis of wastewater sludge has also been practiced to produce a marketable by-product (absorbent materials). The pyrolysis unit generally consists of a closed stainless steel cylinder, in which the sludge is retained for 60 to 90 minutes in the absence of air at a temperature of 1200°F.

The main objectives for the application of physical, biological and chemical processes in a wastewater treatment plant are to remove and concentrate that portion of the wastewater that is responsible for its offensive nature. The sludge which constitutes a significant portion of the total pollutants removed is by far the most important by-product of the wastewater treatment processes. Handling and disposal of such concentrated pollutants present some of the most complex problems that engineers and plant operators face. In addition, the cost of the sludge treatment and disposal is very high/as much as 50% of the total capital and operating costs of the entire waste treatment processes.

Sludge consists of a mixture of organic, and inorganic solid phases, suspended in an aqueous solution. Sludges are the solids which settle from the water and wastewater, and the colloidal particles that are precipitated by biological flocculation and chemical coagulation. The sludge has a very high moisture content ranging from 90 to 99%.

The characteristics of the sludge are dictated by such factors as: source of the wastewater, i.e., municipal, or municipal combined with industrial; the degree of treatment the wastewater receives, i.e., primary, secondary, advanced, or any combination of the above; the type of treatment processes to which the sludge is subjected, i.e., raw (untreated), digested, digested and elutriated; and the type of collection system, i.e., separate or combined systems. In a municipal water treatment plant, sludge is obtained from two major sources: sedimentation basins, and filter backwashes. The characteristics of this sludge depend upon the source of the raw water and the type of the processes utilized.

The quantity of sludge generated by municipal wastewater treatment plants throughout the U.S. is about 13 million tons/year on a dry solids basis. Intensified water quality enhancement programs, stringent water pollution standards, and the construction of additional wastewater treatment facilities, and/or the upgrading and expansion of the existing facilities, and the continual growth of population will contribute significantly to the increase of the sludge quantities being produced. The quantities of sludge produced by water treatment plants are far less than those produced by wastewater treatment plants, amounting to 4 million tons/year on a dry solids basis in the U.S.

In general, primary sludge is gray in color, slimy in nature, and gives off an offensive odor. It has solids content ranging from 1 to 5%. Activated sludge is generally brown in color. When the color darkens, it indicates septic conditions. The fresh sludge has no characteristic odor, but in septic conditions it has the disagreeable odor of putrefaction, and the solids content ranges from 3 to 8%. Trickling filter humus has a brownish color;

the fresh sludge has relatively inoffensive odor, but when it undergoes decomposition, it gives off a very offensive odor. The solids content of the humus ranges from 3 to 7%. Digested sludge has a dark brown to black color and contains large quantities of gases. A completely digested sludge has an odor similar to that of hot tar or burnt rubber. It has solids content ranging from 0.2 to 4.0%.

The solids fraction of the wastewater sludge is primarily composed of biodegradeable material (30%), stable organic matter (35%), and inert material (35%). Further, about 60% of the total solids are dissolved solids, 20% are settleable solids, and 20% are colloidal solids.

The characteristics effecting ultimate disposal and effective utilization of the wastewater sludges include: settling characteristics, specific resistance, flow characteristics, calorific values, chemical composition, and fertilizing ingredients of the sludge.

Settling characteristics of the sludge are vital parameters, since one of the primary objectives in sludge treatment is to concentrate the residues and reduce the overall volume of the sludge. In the design of treatment processes, zone settling and compression settling are of major importance; however, discrete settling and flocculant settling may also occur at a given period during sedimentation. The Talmadge and Fitch method is generally applied to determine the settling tank area requirements for both sludge thickening and clarification purposes, for zone settling. The concentration of the settled sludge is effected by such factors as: wastewater characteristics; type of biological treatment the wastewater receives; design and operation of the settling tank; promotion of settling, using mechanical means or chemicals; settleable solids characteristics; solids concentration in the original suspension; and sludge detention time, etc. The solids concentration of the sludge varies from 0.5 to 10% for raw sludges and from 2 to 10% after digestion.

Another physical characteristic of the sludge that is important in the design of treatment processes such as vacuum filters, centrifuges, and drying beds is the specific resistance. A specific resistance concept is generally used to evaluate the filtration characteristics of the sludge; by this is meant the difficulty encountered in removing water or conversely, the ability of the sludge to retain water. Specific resistance values for wastewater sludge range from 10×10^7 sec^2/gr, when chemical coagulants are employed, to as high as 2800×10^7 sec^2/gr for pure activated sludge. Low values are indicative of a sludge with rapid draining or filtering characteristics, and for high values the reverse is true.

The heterogeneous nature of the wastewater sludge causes complex flow phenomena; consequently, the direct application of the existing hydraulic equations for measuring pipe friction loss is not adequate in most cases. Flow characteristics of the sludge become a significant parameter when liquid sludge is transported via pipelines to the disposal site. The most significant factor effecting sludge flow is the moisture content of the sludge. Based on the moisture content, the flow is classified as: (1) flow in suspension, and (2) plastic flow. Numerous methods for calculating critical velocities, head loss, and other flow characteristics are available in the literature.

Calorific value of the sludge is a vital parameter in the design and operation of sludge incinerators. Calorific value of the sludge combined with its ultimate analysis determines the quality of the sludge for incineration. The combustible fraction of the sludge ranges from 50% for digested sludge to 75% for raw sludge. The heat content of the sludge ranges from 5000 Btu/lb to 14, 000 Btu/lb of combustible solids, for digested and undigested sludges respectively.

A proper assessment of the usefulness of the sludge can be made if its chemical composition is known. Analysis of the specific organic constituents of a sludge is important in predicting what conditions will prevail during dewatering and also helps in determining what specific effects the sludge might have on solids characteristics. The organic fraction ranges from

60 to 80% on a dry weight basis, for primary sludge; 62 to 75% for activated sludge; and 45 to 60%, for digested sludge. The organic content of the sludge is usually measured from the BOD and volatile solids determination. However, more useful and implicit tools are the COD and TOC tests. Sludge also contains a variety of metallic ions, including toxic metals. Their relative concentrations depend mainly upon the origin of the wastewater.

Wastewater sludge contains many fertilizing elements. In comparison with commercial fertilizers, they are rated principally on their content of three substances: nitrogen, ranging from 0.8 to 10% as N; phosphorous, ranging from 1 to 4% as phosphoric acid; and potassium, ranging from 0.1 to 0.5% as potash.

Characteristics of the sludges from water treatment plants are highly variable depending on such factors as: sources of raw water; type of treatment processes employed; type of chemicals added; efficiency of unit operation; degree of solids removed; and the time between basin and filter backwash clean-out. The significant parameters for characterizing these sludges include: solids; settleability; filterability; viscosity; and to a lesser extent, coliform content, BOD, COD and chemical composition.

The two major types of sludge resulting from a municipal water treatment plant are: (1) basin sludges, and (2) filter backwash wastes. Basin sludge is comprised of the organic, inorganic, and biological organisms present in the raw water and may be in a state of solution, colloidal suspension or readily settleable form; or, it may be mixed with coagulant aids employed in the treatment process. Basin sludge appears as a fluffy agglomeration of chemically precipitated and organic debris, with a high moisture content (96-99%). The color of the sludge approaches yellow-orange, pale-green, dark-brown and sometimes black, depending upon the type of chemicals used, nature of the impurities extracted, and stage of decomposition of the organic material. Filter backwash waste essentially contains a finer fraction of the basin sludge in a much lower concentration, plus a small portion of the filter media itself.

The ultimate disposal of the vast quantities of sludge being generated throughout the U.S. is one of the most complex problems facing sanitary engineers today. It appears that the disposal problem will continue to grow due to tightening of water, air and land pollution control standards, lack of land availability resulting from rapid growth of urbanized communities, growth of population, etc.

Numerous methods for disposal or utilization of municipal sludges have been practiced. These methods are summarized in Table 1. Ultimate disposal of the sludge is the last step in the treatment processes. It must comply with the state, interstate and federal standards and requirements; it should not adversely effect the surface or ground water, air, or land surfaces; it should be economically feasible; and it should assure public health safety.

Ocean disposal of wastewater sludge by barging or through submarine outfalls is very common practice for major coastal cities. It is the most economical disposal method for coastal cities when compared with the alternative methods. However, because of the observed adverse environmental effects of this method, indications are that this method may be banned in the future.

Land spreading of treated liquid sludge on crop lands appears to have gained much popularity in the last decade. It offers many advantages, including: (1) economy; (2) recycling of water, nutrients, and organic materials; (3) a final treatment process and ultimate disposal; and (4) freedom from nuisance if done properly. Possibilities of toxic metal accumulation and surface and ground water contamination appear to be negligible; however, extensive research is required to confirm this.

Wastewater sludge has been utilized to reclaim sandy soils and strip mine spoils by converting them into valuable crop land or recreation parks. Numerous projects throughout the U.S. are underway. It appears that this is a satisfactory method of sludge disposal to the extent that it does not cause pollution; it is relatively economical; and it utilizes the organic content of the sludge for beneficial purposes.

TABLE I

PRESENT METHODS OF MUNICIPAL SLUDGE DISPOSAL AND/OR UTILIZATION

Wastewater Treatment	Water Treatment
1. Ocean dumping or discharging.	1. Direct discharge to streams, ocean or lake.
2. Land spreading of liquid sludge.	2. Lagooning of the sludge.
3. Land reclamation.	3. Agriculture utilization.
4. Lagooning and landfilling.	4. Discharge to sewers.
5. Disposal of dried sludge as fertilizer or soil conditioner.	5. Disposal in sanitary landfill.
6. Underground disposal.	6. Application of sludge to strip mines.
7. Incineration and landfill of ash.	7. By-product recovery.
8. By-product recovery.	

Application of dried treated sludge on land as fertilizer, or soil conditioner is a viable ultimate disposal method. From the standpoint of fertilizing ingredients content, dried sludge may not compete with commercial fertilizer, however several municipalities have reported satisfactory marketing of the dried sludge. A growing demand for the use of dried sludge on parks, golf courses, and lawns is apparent.

Recovery of certain by-products such as Vitamin B-12, grease, metals (Ag, Cu, Ti, etc.), absorbent material, etc. from wastewater sludges has been reported in the literature. However, marketing and the value of the product and associated marketing problems have not been worked out. In general, the market place determines the by-product specifications; and, in most cases, the specifications are rigid concerning product purity and concentration. A great amount of development and additional research needs to be done before by-product recovery appears to be practical.

Disposal of the sludge generated from municipal water treatment plants has been predominantly dumped into the nearest available water course. It appears that an intensified effort is in progress by the water industry and other organizations to put the task of handling and disposal of these wastes in the proper perspective. A majority of the states has banned direct discharge of these wastes into state or federally owned waters. Methods for disposal and utilization of these wastes presently in use are listed in Table 1.

Direct disposal of these wastes into a water course may not cause serious health hazards as compared with wastewater and wastewater sludges, because of low organic content. However, the high solids content of these sludges may color the receiving water, increase its turbidity, and may settle and form sludge beds, interferring with the natural aquatic life cycle. Disposal of these sludges into sanitary sewers has resulted in enhancement of the wastewater treatment process operation. However, it has some disadvantages, including precipitation and solids formation on the walls of the sewers if flow velocities are below 25 ft/sec; and in excessive amounts it may hinder the biological activities of the secondary process. Disposal of these wastes into sanitary landfills appears to have many advantages. However, leaching has been reported when liquid sludge was applied in excessive amounts. Application of water softening plant sludge as an agricultural lime, or for reclaiming strip mine spoils has shown very promising results. When used as agricultural lime, care must be taken so that possible accumulation of toxic metals is prevented.

By-product recovery of the wastes from water treatment plants includes lime recovery, magnesium recovery, and alum recovery. Recalcination (lime recovery) from large softening plants has been very successful and has almost eliminated the disposal problem. Recovery of magnesium carbonate and utilization of it as a replacement for alum coagulant seems very promising. Recovery of aluminum sulfate from water purification wastes has been practiced very extensively in Japan and France. Although this process substantially reduces the volume of sludge for final disposal, complete separation of the impurities, such as iron, manganese, etc. is a difficult job.

UTILITY COAL ASH

The burning of coal produces an ash residue which is derived from the inorganic mineral constituents in the coal and the organic material not completely burned. In coal burning utility boilers, the coal ash residue is collected from the bottom of the boiler unit (bottom ash) and from the air pollution equipment through which the stack gases pass (fly ash). Over 46 million tons of coal ash were collected in 1972 by some 500 power plants in the United States. The distribution of power plants defines the ash producing regions of the country. The largest concentration of power plants is in the middle Atlantic and the east north central states. There are very few coal burning power plants west of the Mississippi River.

The coal ash residues recovered from the boiler units are primarily iron aluminum silicates with additional amounts of lime, magnesia, sulfur trioxide, sodium oxide, potassium oxide, and carbon. About 12 percent of the coal burned is recovered as coal ash residue. A high percent of that ash is in the glass state (50-90 percent), with small quantities of quartz, mullite, magnetite, and hematite mineral phases. An average chemical analysis for coal ash would be:

SiO_2	45%
Al_2O_3	25%
Fe_2O_3	14%
CaO	4%
MgO	2%
TiO_2	1%
K_2O	2%
Na_2O	1%
SO_3	2%
C	4%
B, P	Trace

Mn	
Mo	
Zn	Trace
Cu	Trace
Hg	Trace
U	Trace
Th	

The specific chemical composition of a coal ash is primarily dictated by the geology of the coal deposit and the operating parameters of the boiler unit.

About 70 percent of the coal ash residue is collected as fly ash. For any specific boiler unit the fly ash and bottom ash will have essentially the same chemical composition except that the bottom ash will be lower in carbon content. Fly ash generally occurs as fine spherical particulates having an average particle diameter of 7μ. The fly ash will range in color from light tan to black, depending on the carbon content, and have an average specific gravity of 2.3. The pH of the fly ash will vary from 6.5 to 11.5 and will average about 11. About 20 volume percent of the fly ash will be composed of very lightweight particles which float on the surface of the ash lagoon. These lightweight particles have a true density of about 0.5 g/cc and are termed cenospheres. These cenospheres are carbon dioxide and nitrogen filled microspheres of silicate glass ranging in size from 20μ to 200μ.

The bottom ash is collected either as an ash or a slag depending on the particular boiler design. The ash material is grey to black in color, quite angular and has a porous surface. The slag particles are normally black angular particles having a glass appearance. The bottom ash particles will have an average particle diameter size of 2-1/2 millimeters and an average specific gravity of 2.5.

Advancing boiler design technology and the establishment of stricter air pollution codes for boiler facilities may alter the nature of the coal ash produced in future years. The various proposed desulfurization processes, coal fractionation processes, and new designs for electric generating facilities can result in coal ash and slag products considerably different from those currently being produced.

The coal fractionation processes used for obtaining clean gas or liquid fuels and the reconstitution of the coal to obtain a clean low-ash, low-sulfur fuel results in the production of slag and char residues at the conversion facility rather than at the power plant. The liquefaction process produces a filter cake of inorganic materials. The fluidized-bed gasification generates a powder waste composed of the fluid media, the coal residue, and a calcium sulfate precipitate. In the high temperature gasification process the residue is a glassy slag. The chemical composition and physical characteristics of these residues have not been well defined due to the relative newness of these processes.

Conversion of existing boiler units to fluidized bed units will result in a change in the nature of the coal ash recovered. Ash from this process will be less vitrified, due to the lower operating temperatures. Also, the quantity of crystalline material increase (quartz, magnetite, alumina, and calcium sulfate) and the alkaline content is likely to be higher.

Several processes have been developed for meeting the newly established codes for control of SO_2 emissions from stationary sources. A number of these processes completely alter the nature of the collected fly ash and others add a new residue material to the solid waste stream. Most of these processes require the wet or dry injection of an alkaline powder (limestone, dolomites, etc.) to absorb the gaseous sulfur in the stack effluent. The wet injection or scrubbing process (limestone) which appears to be more prevalent, in most cases, results in the generation of a new waste ($CaSO_4$) rather than modifying the fly ash. Preliminary calculations indicate that these wastes will most likely result in a doubling of utility residue waste. Since these desulfurization processes are still largely in the development or pilot state, it is not possible to adequately define the chemical characteristics at this time.

Since 1966, coal ash utilization has fluctuated around 15 to 16 percent of the total ash collected in the United States. From data supplied by the Edison Electric Institute it is apparent that the single largest application for coal ash is as mineral fill material for roads and other construction products. Average European usage of bituminous coal ash for 1972 was almost 27 percent and in Belgium, France, Poland, the United Kingdom, and West Germany, usage exceeded 50 percent. The two largest applications for European coal ash were filler on construction sites and for concrete block.

Although a multitude of technically sound applications have been developed for the utilization of coal ash, usage has been very limited. Yearly fluctuations in the quantities of coal ash used in the various applications developed, would suggest that firm markets have not been established for these coal ash uses. At the present time, appreciable quantities of coal ash are only being used as fill material for roads and other construction projects. The use of coal ash as a replacement for cement in concrete and concrete products is starting to increase and a more stable market is being established. The use of fly ash in concrete offers a number of technical advantages, e.g., improved mechanical strength and improved resistance to sulfate leaching, etc. Fly ash, and boiler slag are also being used to an appreciable extent for road base stabilization and as filler in asphalt. Boiler slag is particularly noted for increasing the skid resistance of asphalt pavement. The use of coal ash as a raw material in the manufacture of Portland cement is another application where usage has increased during the past several years. Recent research results indicate that large quantities of coal ash can also be effectively used for agriculture, land, and water reclamation projects. Fly ash has been effectively used in reclaiming surface mine spoil (high pH of ash neutralizes mineral soil), as a soil nutrient, and as an aid in the treatment of polluted waters.

A number of the applications developed for coal ash have the potential to utilize the entire quantity of ash generated. These include agriculture and land recovery, road base stabilization, structural fill, and cement and concrete products.

Effective utilization of coal ash in the many defined applications requires that the potential user be favorably impressed with the product and the product be economically advantageous. The economic competitiveness of coal ash is impaired by the discriminatory federal practices that favor virgin materials in freight rates and depletion allowances. Improved federal economic policy toward secondary materials like coal ash would enhance their utilization potential.

CONCLUSIONS AND RECOMMENDATIONS

In 1972, approximately 46 million tons of coal ash were collected from the burning of some 350 million tons of coal in over 500 utilities. About 16% of the ash collected was utilized. Therefore, over 38 million tons of ash had to be removed to disposal sites at the expense of the utility. At the present time, disposal costs are approaching $2.00/ton of ash disposed. By 1980, coal consumption by the utilities, to meet expanding energy needs, is predicted to be almost 500 million tons. The projected increase in coal consumption coupled with the decreasing quality of available coal (higher ash content) will result in substantially increased quantities of coal ash. Stricter air pollution codes (reduction of particle and sulfur emission) will also result in an increase in the quantity of coal ash collected.

The technology for a diversity of applications, for coal ash, has been well established. The potential market for most of these applications is quite good and several of these applications have potential markets which can utilize all the ash collected. The major need at this time is the initiation of programs which will encourage greater use of the coal ash in these applications. With the anticipated increase in coal ash collected and the increase in disposal costs, the need for programs to stimulate ash utilization becomes more important. Some study should be devoted toward determining the types of programs best suited for effectively stimulating increased ash utilization. Studies characterizing ash residue from fluidized bed boiler units, gasification and liquefaction processes, and desulfurization processes are needed if effective utilization technology for these wastes are to become available. Further, implementation of these new processes will result in the generation of new waste products that can significantly add to the disposal problem unless applications for these materials are available.

MUNICIPAL INCINERATOR RESIDUES

Incineration is utilized for the disposal of approximately ten percent of the collected municipal refuse, on a national basis. Annually, from 16 to 18 million tons of refuse are incinerated. It is estimated that in 1972 about 193 incinerators were operating in the U.S. providing a total capacity for approximately 71,000 tons of refuse per 24 hour day. From the reported data, it appears that most incinerator facilities operate at about 70% of their rated capacity. Most of the incinerators are located in the eastern U.S. with New York, Massachusetts, Connecticut, Florida, and Ohio having the largest number of incinerators. Since 1969, construction of new incinerators or rebuilding of existing facilities has decreased significantly. It appears that the major factors for this decrease are the higher costs of incinerator construction, and higher operation costs due to the institution of stricter pollution regulations for incinerator operations. Capital costs for an incinerator range between $6,000 and $10,000 per daily ton and operating costs range between $5 and $20 per daily ton.

During incineration, furnace temperatures are between 1800°F and 2000°F with flame temperatures at approximately 2500°F. This process results in the reduction of the refuse incinerated to between 25 to 35% of its original weight; and, on the average, to less than 10% of its volume. The resultant residue after quenching is a wet, complex mixture of metal, glass, slag, charred and unburned paper, and ash. The typical range of values obtained for the various residue components is presented below.

RESIDUE COMPOSITION (%)

Material	Range
metals	20-40
glass	10-55
ceramics, stones	1-5
clinker	15-25
ash	10-20
organics	1-10

On a national basis, 4 to 6-1/2 million tons of incinerated residue are generated annually, containing about 1-1/2 to 2 million tons of ferrous metal, 100,000 to 200,000 tons of nonferrous metal and 2 to 3 million tons of glass. In addition to the residue, about 1% of the refuse exits with the exhaust gases leaving the furnace chamber. The particulate matter (or fly ash) retained is predominantly minus 200 microns in size, and consists of wood and paper ash, aluminum foil, carbon particles, metal pins and wire, glass, sand and iron scale. The chemical analysis of this material is very similar to fly ash from coal burning boilers.

The majority of the incinerator residue and fly ash is disposed of by burying. However, some problems are associated with this method of disposal because of potential water pollution from the water soluble portion of the residue. Depending on the specific residue, from 1 to 6% is water soluble. In addition to land fill, some communities are using the residue as a filler for road construction (road bed). The City of Baltimore is screening out the fine fraction for use as aggregate in asphalt. Several cities are salvaging the metal cans from the residue for the copper smelting industry and for use in the manufacture of Rebar. Several studies are now in progress to develop the technology for recovering the glass and metal fractions from incinerator residue. A pilot project by the Bureau of Mines has been relatively successful in developing a system for recovering the glass, ferrous metal, aluminum and other nonferrous metals from the residue. A breakdown of the various products which would be recovered from a 250 ton per day facility is presented below:

QUANTITIES OF THE VARIOUS PRODUCTS RECOVERED FROM THE BUREAU OF MINES' INCINERATOR RESIDUE RECOVERY PROJECT*

Project	Tons/Day
+4 mesh iron	41
-4 mesh iron	35
aluminum	4
copper and zinc	3
colorless glass	69
colored glass	50
waste solids	48

*for a plant processing 250 tons/day

A demonstration facility for residue recovery is scheduled for operation by 1975, at Lowell, Mass. The quality of the products recovered from the residue and the economics of recovery have not been well determined. Preliminary estimates indicate that a plant to process 50 tons per day in an eight hour shift would cost about 2 million dollars and operating costs would be 9 to 11 dollars per ton of residue processed.

The degradation of the metal and glass resulting from the incineration operation may limit the market acceptance of these materials. During incineration the ferrous metal is contaminated by copper and tin and undergoes considerable oxidation. The glass is subjected to slagging and contamination from metal and other minerals. Estimates for the revenue from the products of a ton of residue have varied from $6 to $15. For distant markets, freight rates become a major factor in the economics of the recovery process; and this is further compounded by the higher rates for secondary materials. In the final analysis, the economic viability for these recovery processes has yet to be firmly established and until an actual unit is in operation, it will not be possible to make a final determination on this matter.

The high cost of incineration, the institution of stricter pollution codes, and the increased need for the conservation of national resources suggests an uncertain future for conventional incineration, as indicated by the reduction in the construction of new facilities. The development of advanced combustion processes for urban refuse would appear to have a more promising potential. The advanced processes under development include: waste heat recovery for steam generation; high temperature incineration; fluidized bed incineration; pyrolysis and hydrogenation of refuse and the processing of refuse for use as a low-sulfur fuel supplement for coal burning furnaces and boilers. The residue from many of these processes will be considerably different from that obtained by conventional incineration. In high temperature incineration, combustion is more complete. All the organics are eliminated and the glass and metal is melted forming a slag, which after quenching is a good aggregrate material. In the fluidized bed process, the refuse is usually shredded and the metal removed prior to combustion. The residue is a powdery inorganic ash. Waste heat recovery for steam generation can be incorporated with conventional incineration as well as with high temperature and fluidized bed incineration. The nature of the residue will be determined by the precombustion processes (metal, glass removal, etc.) and the temperature of combustion. In the various pyrolysis processes the refuse is shredded and the metal and glass removed prior to the destructive distillation of the organic materials. One ton of refuse will yield from 154 to 230 pounds of char residue by this process. The shredded refuse with the glass and metal removed can also be effectively used as a low-sulfur fuel supplement. The residue from the refuse in this case would be combined with the coal ash and recovered from the pit (bottom ash) and from the air pollution equipment (fly ash). In all of these advanced processes, the residue produced is primarily recovered as ash which can be used as fill in various construction applications. Removal of the glass and metal prior to combustion results in a residue that is easier to utilize and provides metal to glass fractions of higher quality. The economics for the different refuse disposal and recovery processes have been compiled by Midwest Research and are presented next for purposes of comparison. These data were compiled in 1972 and are based on the economic conditions at that time. Although the specific numbers quoted are not out of date the economic ratio between systems is still relatively valid.

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16. ABSTRACT

The nature and disposal practices for municipal and utility sludges and ashes were studied. The study was primarily concerned with the sludges from municipal waste water, and water treatment plants, coal ash from power stations and grate residue from municipal incinerators. Each of these subject areas is presented in a separate report. Volume I of this series presents the summary for the results and conclusions developed for each of the subject areas.

17. KEY WORDS AND DOCUMENT ANALYSIS

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