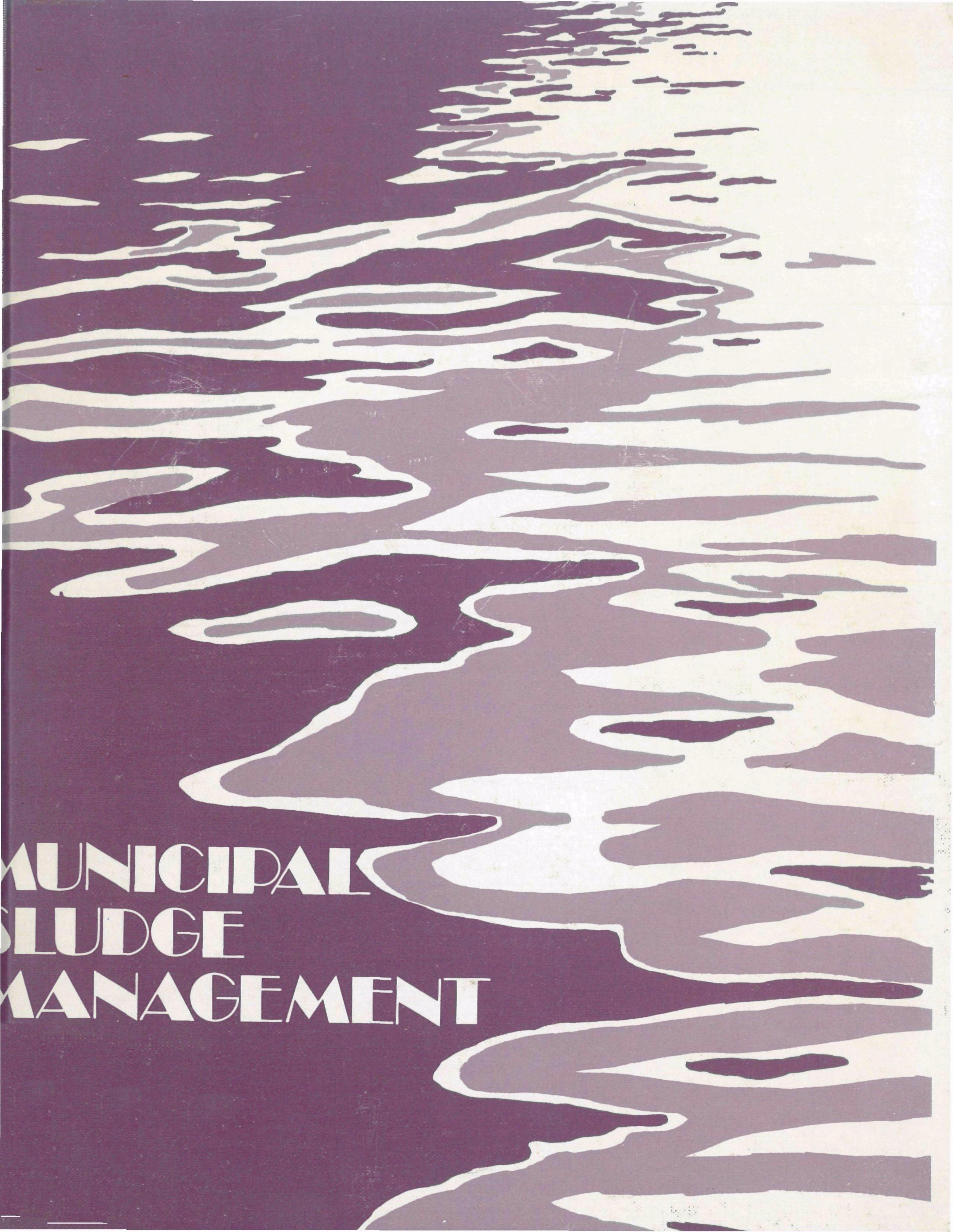
MUNICIPAL
SLUDGE
MANAGEMENT

MUNICIPAL SLUDGE MANAGEMENT

PROCEEDINGS OF THE
NATIONAL CONFERENCE
ON MUNICIPAL
SLUDGE MANAGEMENT

JUNE 11-13, 1974
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MUNICIPAL SLUDGE MANAGEMENT

KEYNOTE ADDRESS

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Wearing another hat, I want to take this opportunity to extend words of welcome from the Board of Commissioners of Allegheny County. Our involvement in a conference of this type, I believe, indicates our concern about environmental problems and our willingness to try to do something about correcting them.

As background information, you should know that Allegheny County put into operation the first automatic telemetered air pollution monitoring system in the United States. The data collected has been used in enforcement proceedings instituted by the County and is also a vital part of a warning system which enables us, with the cooperation of industry, to control emissions from certain plants during times of weather inversions.

Our Works Department is actively engaged in implementing a solid waste management program, and we are assisting local municipalities in implementing regional sewage systems. Our Conservation District is involved in surveillance of erosion and siltation problems. Our Health Department, in addition to its work in the air pollution field, is the regulatory agency in matters relating to solid waste and sewage problems. One part of this latter program—the proper handling of municipal sludges—is the subject for discussion at this conference.

I believe it was Barry Commoner, in his book, *The Closing Circle*, who pointed out four basic rules which we must adhere to in finding solutions to environmental problems. Rule #1 states that we never throw anything away. Rule #2 states that everything we do is connected to everything else. Rule #3 states a well-known fact that nature knows best. And Rule #4 states a fact that we are constantly faced with—"There is no such thing as a free lunch."

With these items as focal points, this august body will, I trust, help to find ways and means for sludge management which are equitably, economically and environmentally acceptable.

We have come to realize that the first rule, "Nothing is ever thrown away," has a great deal to do with how we proceed. In our attempt to clean up the air and water, we sometimes forget that what we have taken out of these two elements must still be dealt with. In the field of sewage treatment, the problem of sludge management is one which has plagued many engineers and government officials during the past several decades. It has almost become a critical situation, since we are building more treatment facilities and expanding existing treatment facilities in order to take more of the pollutants from the water before it is discharged to the receiving stream. No longer can we afford to haphazardly dump sludge on barren land or at sea. No longer should we burn sludge just for the sake of disposing it. No longer will we be able to live with the premise that *if you can't see it, it isn't there.*

Many experiments have been tried nationwide. Some have been successful and some have shown that additional questions have yet to be answered. I trust that the discussions at this meeting will enable pertinent information to be passed back and forth among those who are seeking solutions. Here again, in Allegheny County, we are attempting to solve this sludge problem with a variety programs.

We cannot, however, in any future efforts, forget Barry Commoner's second rule, "Everything is connected to everything else."

For the past several decades, this country has lived with the belief that bigger is better. We have grown, we have developed and we have built without any true regard for the after effects of major disruptions of natural areas. We are now finding that although we live better, and have more conveniences than our fathers thought possible, we have also created problems which at times seem to be unsolvable. We then have two areas of concern. The first is to try to catch up with ourselves and repair the damage which we have done; and the second is to see that, in any of our planning for the future, we do not get into the same bind in which we now find ourselves.

Paraphrasing Dr. Commoner's second rule, every action has an equal and opposite reaction. We *must* remember that the environment is everything around us and when we change something, as we must because of the wants and needs of our increased population, there *will* be an after effect or reaction which must be considered in the original instance.

Although the brunt of your discussions will be aimed at municipal sludge or that which comes from treating sewage emanating from homes, businesses and commercial establishments, we cannot forget, especially in urban areas, the industrial sludges which are developed as a part of industry's program of cleaning up their discharges.

These materials are complex, not only in individual plants, but when considering the types of operations carried on in all of the industrial activities in this area, the variation in composition sometimes boggles the mind.

In addition to municipal sludges and industrial sludges, we also face the problem of effective utilization of the *solid* waste or refuse which is generated in the homes, businesses and industries in this country. It seems to me, that the brains in this room should be able to develop some means whereby these three types of wastes—sewage sludges, industrial sludges, and solid materials—could be effectively reused in some manner, either singly or in combination with one another.

In coming to grips with this expanded scope, we cannot forget Commoner's Rule #3, "Nature knows best." While I have a great deal of respect for engineering talent and wholeheartedly believe that man's ingenuity is boundless, I also am firmly convinced that there is really nothing new under the sun. The basic facts of chemistry, physics, electricity and strength of materials have all been well established through the ages. For many hundreds of years man has known about the problems associated with the disposal of his wastes. For centuries, shepherds have known that the droppings from sheep could be used as a heat source and swamps have always given methane gas as a result of the decomposition of organic materials. It seems to me that what is required in today's civilized society is an attempt to use the basic laws of nature to our advantage rather than to attempt to circumvent them.

While the basic technology is known, our problem—yours and mine—is to scale up our laboratory or demonstration models to a working size large enough to handle the problem in a given area. Remember, however, that a regional *plan* does not necessarily mean a regional *plant*—or we would have one huge sewage treatment facility in New Orleans serving the Mississippi and Ohio River drainage basins.

Let me now go on to Rule #4 which in the minds of many citizens is the most important—"There is no such thing as a free lunch." Development and building and expansion cost money. During the course of that development, building and expansion, and as a result of that development, building and expansion, wastes are generated. These materials, however, are wastes only in the eyes of those actually involved in the initial growth and in the eyes of those who are benefiting from the fruits of that growth. It's readily easy for a consumer to accept the fact that he has to pay for something required to build his house or brought into his home, office or business. It is not so easy to see that the material that he no longer wants or needs must be taken away and that there is also a cost associated with that operation. My concern, and your problem, is to see that Dr. Commoner's first three rules are adhered to at as low a cost as is possible, given the fact that protection of the environment *must* be one of our ultimate goals.

I'd like to speak to you for a few more minutes about two additional rules which cannot be ascribed to Dr. Commoner.

The first one goes back about a century when Abraham Lincoln said, "You can't please all of the people all of the time." In the context of municipal sludge management, I am sure that *whatever* solutions may eventually evolve, we will have theorists, purists, environmentalists, governmental officials and just plain citizens, who will decry our efforts. I am just as certain, however, that Berman's Rule *must* be implemented. This dictum states that while we can do as much planning and discussing of numerous alternatives as we care to, while we can develop all types of "systems" approaches, and while we can develop "models" to our heart s content, no *one* solution will ever solve *all* of our municipal sludge problems. Rather, a series of approaches are required which, I am confident, will eventually lead to the gradual elimination of the seemingly gigantic problem which faces us today.

Being an eternal optimist, I am confident that our sludge management problems will be solved deliberately, rationally, and *slowly—but inexorably.*

OVERVIEW OF SLUDGE HANDLING AND DISPOSAL

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For about eight years, the Advanced Waste Treatment Research Laboratory, which is now part of U. S. Environmental Protection Agency's National Environmental Research Center, Cincinnati, has had an Ultimate Disposal Section. A primary objective of this group has been to advance the technology for processing and disposing of the concentrates from municipal and advanced wastewater treatment processes. It has thus been our privilege to observe and to take part in the effort to improve the methods for handling and disposal of wastewater sludges.

As the quality of wastewater treatment has improved, sludge handling and disposal have become a greater problem. The trend is not expected to change. As more and more municipalities upgrade facilities to improve effluent quality, the quantity of sludge will continue to increase. Table 1 compares sludge production in 1972 with the estimated production in 1985: the amount of secondary treatment sludge will be almost doubled, and chemical sludges will be produced in quantity; dewatering costs will increase more than proportionately because the biological secondary sludges and several important types of chemical sludges are unusually difficult to dewater.

The operations carried out on wastewater sludge are conveniently divided into treatment operations, such as pumping, thickening, stabilization, and dewatering; and disposal operations, which include

TABLE 1
Trends in Production and Disposal of Municipal Wastewater Sludge

	1972		*1985*	
SLUDGE TYPE	*Popul. (mill.)*	*Dry tons** per year*	*Popul. (mill.)*	*Dry tons per year*
Primary (0.12 lb/cap-day)*	145	3,170,000	170	3,720,000
Secondary (0.08 lb/cap-da)	101	1,480,000	170	2,480,000
Chemical (0.05 lb/cap-da)	10	91,000	50	455,000
	Percent		*Percent*	
DISPOSAL METHODS				
Landfill	40		40	
Utilized on land	20		25	
Incineration	25		35	
Ocean (dumping and outfalls)	15		0	

*lb x 0.454 = kg.
**ton x 0.908 = metric ton.

incineration, landfill, and landspreading. The more important recent developments in treatment are considered here first.

Treatment Operations

Thickening

If sludges removed from primary and secondary clarifiers are to be dewatered, their solids content should be as high as possible, that is, just short of the point where the "thick" sludge interferes with the operation of the device used for dewatering. Thickening is often required. The most commonly used devices are either gravity or air flotation thickeners. Air flotation thickeners are generally more expensive to operate, but have advantages in certain cases. There is less opportunity for sludge to become anaerobic, because residence time is less than in a gravity thickener and air bubbles that have floated the sludge provide a reservoir of available oxygen. In secondary plants where the effluent has nitrified, gravity thickening of waste activated sludge becomes difficult because the respiring activated sludge organisms use nitrate as their oxygen source after dissolved oxygen is consumed. Nitrogen gas is released and this causes a portion of the sludge to float. If air flotation is utilized instead of gravity thickening, any tendency of sludge to float will, of course, be advantageous.

Stabilization

The conventional stabilization processes are anaerobic and aerobic digestion. The effect of these processes is to reduce odor, reduce the putrefaction potential of the sludge, and reduce the concentration of hazardous microbiological organisms. It is interesting to separate these positive results and consider other means by which they can be carried out. Table 2 measures a number of processes against these characteristics. It is evident that none of the processes do all things well. Further study of Table 2 indicates that certain combinations of processes would be effective, for example, anaerobic digestion followed by pasteurization. These two processes have been carried out in sequence in Germany[1] to treat sludge used on pasture lands during the summer months. Radiation has recently been used following anaerobic digestion[2], again in Germany and for the same purpose.

Costs of combined treatment are additive. Recently, however, there has been interest in the use of anaerobic or aerobic thermophilic digestion. These processes can be operated at 60°C and destroy pathogenic microorganisms. They effectively combine pasteurization and stabilization into a single process, and economies can result.

TABLE 2
Attenuation Effect of Well-Conducted Treatment Processes on Stabilizing Wastewater Treatment Sludges

PROCESS	*DEGREE OF ATTENUATION*		
	Pathogens	*Putrefaction Potential*	*Odor*
Anaerobic digestion	fair	good	good
Aerobic digestion	fair	good	good
Heavy chlorination	good	fair	good
Lime treatment	good	fair	good
Pasteurization (70°C)	excellent	poor	poor
Radiation	excellent	poor	fair
Heat treatment (195°C)	excellent	poor*	poor*

*good for filter cake

Most stabilization processes adversely affect supernatants and filtrates from subsequent dewatering operations: anaerobic digestion and heat treatment produce supernatants rich in nutrients and BOD; supernatant from heavy chlorination is high in chloramines and possibly chloro-organic compounds; and supernatant from lime treatment is high in pH. Cost of processing supernatants must be considered in the total cost of processing.

Processes such as digestion and heat treatment reduce the mass of sludge to be treated in subsequent operations. These changes in mass are a cause of great confusion in the literature when costs of complete processing sequences are compared. Costs are most often presented as dollars per ton of dry solids without specifying whether the basis is the sludge mass before or after processing. An unequivocal way of comparing costs of alternative processing sequences for a given wastewater is to base costs on equal wastewater flow (e.g., 1000 gal. of wastewater).

Dewatering

FILTRATION. The continuous rotary vacuum filter is the most commonly used device for dewatering wastewater sludges. Three different types are used: the drum (cloth on drum, cake removed by doctor blade), cloth belt (cloth belt winds off drum, sharp bend causes cake to drop off, both sides of belt are washed, and cloth returns to drum), and coil (filter surface comprises two layers of tightly coiled springs, otherwise similar to belt type).

A new type of drum filter, utilizing top-feed, has been developed by the Rexnord Corporation for the

City of Milwaukee under an EPA grant (see Figure 1). Gravity assists in depositing coagulated solids, which are denser than water, onto the drum surface. Gravity also assists in removing cake from the filter surface, so air blowstack to loosen cake is not needed, and the doctor blade is nearly superfluous.

CENTRIFUGES. Solid-bowl continuous conveyor-type centrifuges are the most popular centrifugal device used for sludge dewatering. Cake solids contents are similar to those obtained with vacuum filters. These devices are also excellent classifiers. They are being used with tertiary[3] and primary line sludges[4] to classify organic and most mineral solids except calcium carbonate, which can be calcined and recovered as CaO.

Basket-type centrifuges are being used to thicken aerobically digested sludge. This type of centrifuge will be used to remove solids from the centrate from Los Angeles County's solid-bowl conveyor-type centrifuges[5].

OTHER METHODS. Filter presses are receiving considerable interest in the United States, particularly now that high cake solids is becoming important. At Cedar Rapids, Iowa[6], a filter press has been installed that uses a precoat of sludge incinerator ash and a body feed of incinerator ash, lime, and ferric chloride. Vertical presses, used at several plants in Japan, offer very speedy cake discharge. Precoat is not needed because a section of the filter cloth is washed during each cycle. The cloth advances one frame at each discharge cycle. Thus, a section of cloth is washed after having performed a number of filtrations equal to the number of frames. $Ca(OH)_2$ and $FeCl_3$ are the usual conditioning agents with this filter at Japanese plants.

Belt filters have been used extensively in Europe and are being marketed in the United States. They combine gravity drainage with mechanical pressure after a cake has been formed. The Carter* belt filter, presented schematically in Figure 2, illustrates the principle. The capillary suction filter developed by Westinghouse with the financial support of EPA combines capillary suction dewatering with mechanical pressure. A simplified sketch of the original research unit is presented in Figure 3. Sludge is placed in a dry belt of a foamed porous material, which removes moisture from the sludge by capillary action. A contact roll rides directly on the partially dewatered sludge layer and applies mechanical pressure. Water is forced from the sludge into the porous belt. The sludge cake transfers to the smooth-surfaced contact roll where it is collected and removed. The porous belt, now free of sludge, is washed and squeezed dry. Activated sludges, which can be dewatered to over 15 percent solids, can be dewatered to over 18 percent solids at high rates with this device.

*Mention of manufacturer's name does not constitute EPA endorsement.

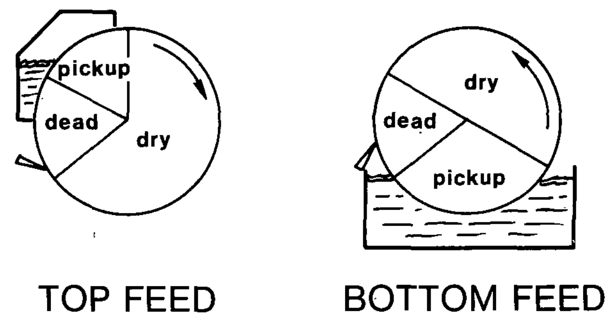

Figure 1: Drum-Type Vacuum Filters.

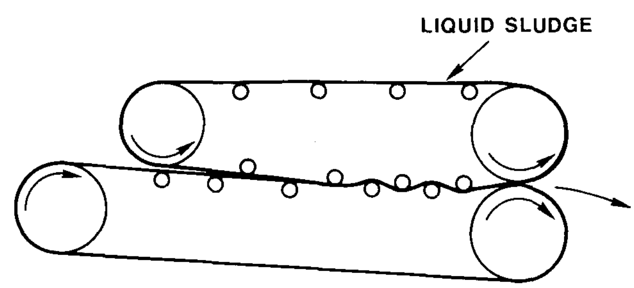

Figure 2: Schematic of Carter Belt-Filter Press.

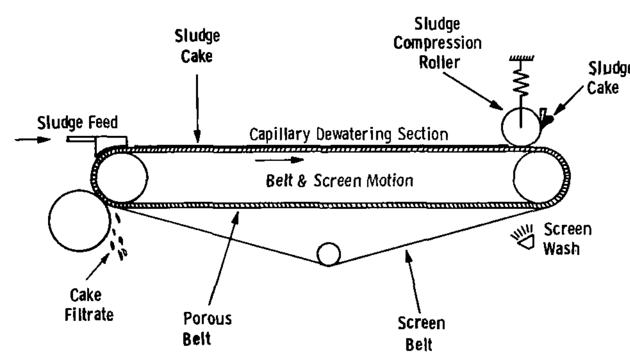

Figure 3: Schematic of Research Capillary Dewatering Unit.

Conditioning

Very few sludges can be filtered without additives of some kind. Lime and ferric chloride continue to be used, particularly when odors are a problem or when improperly digested sludge is to be landfilled. The use of organic polymeric conditioning agents continues to grow. The more rapid gains, however, have been made by heat conditioning. Sludge heated to 200° C (392° F) for under an hour, in the presence of air or without air, loses its gelatinous nature and becomes easily filterable, generally without chemicals. A substantial portion of the sludge, however, is solubilized and the filtrate must be recycled to biological treatment.

Heat treatment is a satisfactory means for conditioning sludge. Whether or not it is the most cost-effective depends on the situation. The process requires a higher degree of operating skill than is ordinarily available at wastewater treatment plants. It causes odors that are sometimes extraordinarily difficult to eliminate. The additional cost of biologically treating the filtrate (and handling the increased biological sludge generated) should be charged to the process. Even for plants with temporary excess capacity, the loss in capacity caused by the need to process recycle streams must eventually be borne by the wastewater treatment plant. In Great Britain, where effluent quality requirements are more stringent than those in the United States, separate treatment of the supernatant is needed. At one facility, supernatant is being biologically treated by separate activated sludge treatment, which is followed by activated carbon to remove residual COD. At another plant, the entire supernatant will be concentrated by flash evaporation and the concentrate then incinerated.

Disposal Operations

Hazardous Substances

Disposal of sludge is turning out to be the pivotal question in wastewater processing. Sludges contain the concentrated wastes of a community. It is reasonable to expect that objectionable materials may be present in sufficient concentration to be hazardous. The degree of hazard will, of course, depend on the intended means of disposal.

Some typical concentrations of hazardous substances found in sludge are presented in Table 3. The hazardous substances are toxic metals, toxic organic chemicals, and pathogenic microorganisms. The concentration and quantities of these contaminants clearly limit disposal options. For example, the high concentrations of pathogens in raw sludge virtually prohibit disposal to landfill or to agricultural land. Sludge with a high PCB concentration should not be applied to land if there is a possibility of leaching. Sludge with high mercury content may be suitable for disposal to a landfill but not for incineration. There appears to be no foolproof disposal method suitable for all sludges.

TABLE 3
Approximate Concentration Levels of Substances in Municipal Wastewater Sludges

Sludge parameter	*Raw primary*	*Digested primary*
% Volatile solids	72.0	52.6
% Ash	28.0	47.4
Metal concentration (mg/kg dry solid)		
Cd		30
Zn		1,950
Cu		1,000
Ni		350
Hg		5
Bacterial content (per 100 ml liquid sludge)		
Fecal coliform	11×10^6	0.4×10^6
Salmonella	460	29
Pseudomonas aeruginosa	46,000	34
Organic compounds (mg/kg dry solids)		
Polychlorinated biphenyls		n.d.* to 105
Chlordane		3 to 30
DDT		n.d. to 1
Dieldrin		0.1 to 2.0

*n.d. = not detectable

The type of disposal chosen by a community is a commitment not easily changed. Increasing knowledge of hazards, or a change in the nature of the community's wastes, may indicate that the wastewater sludges contain too high a concentration of certain materials for the method of disposal practiced. Two things are necessary—the community should have a current knowledge of the concentrations of hazardous materials in its sludge, and it should have ordinances which allow it to prohibit disposal into its collection systems not only wastes which affect the quality of wastewater processing but also hazardous wastes which are not "neutralized" by the disposal method and are a threat to the environment.

The conventional disposal methods are ocean disposal, landspreading, landfill, and incineration. A discussion of ocean disposal is beyond the scope of this presentation. It appears at this time, however, that disposal of sludge solids by outfalls or by dumping will diminish in coming years, and that the level of hazardous materials in their sludges will have to be reduced by communities continuing to use these procedures.

Land Application

The use of stabilized sludge to fertilize agricultural land or reclaim marginal land is a conserving use which has been practiced for many years. Chicago plans to dispose of a major portion of their sludge by this means[7]. Coastal cities are considering it as an alternative to ocean disposal. Attention has been called to possible hazard to crops and to human health from a gradual buildup of toxic metals in soil to which sludge has been applied over a number of years[8]. The U. S. EPA is currently studying suggested guidelines for land application of sludge.

It is likely that some restrictions will be placed on the practice of land spreading. Suggestions have been made to limit both the concentrations of metals such as Cd, Cu, Zn, and Ni in the sludge and the maximum loading of sludges on the land[8], or the maximum loading of the metals on the land[9]. Knowledge of effects of metals in sludge on crops is sparse, which makes preparation of reasonable guidelines difficult. It is expected, however, that for communities with an unusually high industrial component in their wastewater, recommended application rates may be too low for this method to be competitive with alternative disposal means.

Landfill

Disposition to landfill is the most common way to get rid of sludge. Sometimes the landfill is a properly operated sanitary landfill for disposal of solid wastes and sludge. Often the landfill is an uncovered dumping site inside the plant grounds. Small plants often dispose of their sludge to unprotected sites outside their plant limits—sometimes in flood plains and often without cover.

Little attention has been paid to the disposal techniques practiced by small plants. Disposal to sanitary landfills may be impractical because of distance or because sludges are banned from the landfill, and operators often resort to what is essentially uncontrolled dumping. The EPA is sponsoring work by the U.S. Department of Agriculture to develop a method for operating a private sludge landfill in an ecologically satisfactory way with the use of simple farm machinery.

A properly operated sanitary landfill is an excellent place to dispose a sludge high in metals or persistent organic compounds. The site should be located where groundwater contamination is not possible, and any leachate should be collected and treated.

Incineration

When properly carried out, incineration is a satisfactory means of disposing of the great majority of hazardous sludges. Particulates must be contained by modern scrubbing equipment, and temperature-time characteristics must be adequate to decompose thermally stable organic compounds. Sludges containing mercury are an exception because mercury vaporizes upon incineration and is not captured satisfactorily by conventional scrubbers. Even mercury can be captured, however, if the flue gases are brought to room temperature and filtered[10]. A major problem with incineration is poor operation; this can be corrected by good operating procedures and modern control devices.

Trends in Disposal

There has probably not been a more difficult time for forecasting disposal trends. The picture is very negative for ocean disposal, although changes are possible. Land application will be subjected to guidelines—guidelines that will recommend reduced application rates and require more land; landfill is satisfactory, but suitable sites are diminishing rapidly; incineration would appear to face a promising future except that the high cost of fuel, added to the cost of air pollution control equipment, has escalated the total cost.

Promising areas for the future, which are now being seriously investigated, are co-incineration and co-pyrolysis of sludge with solid waste. These methods will not require supplemental fuel. Copyrolysis may produce usuable fuel gas and char. When estimating future disposal trends (Table 1), incineration and pyrolysis increase from 25 percent in 1972 to 35 percent in 1985. Much of this gain will be from new methods of co-incineration and copyrolysis.

Certainly disposal costs, as a proportion of wastewater treatment costs, will rise. The benefit will be a more secure environment for now and for the future.

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ALTERNATIVE METHODS FOR SLUDGE MANAGEMENT

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The treatment of wastewater is usually separated into: 1) treatment of a liquid phase, and 2) treatment of a solid phase. There is a natural interchange between these two phases, but broadly speaking, they are separate. The treatment processes are usually designed very carefully to optimize effluent quality; the sludge handling systems are usually constrained "to do the best we can with what we have". The situation should be reversed.

For example, the separated solids from sewage treatment is generally about 0.5 percent of the total liquid phase volume. However, sludge disposal costs usually represent between 30 and 50 percent of the total costs associated with complete wastewater treatment. With advanced waste treatment doubling the quantity of sludges, this cost ratio will undoubtedly increase. Sludge disposal should receive at least an equal effort in planning, as does the wastewater treatment, if not more. It should not be relegated to being considered only in the final stages of plant design efforts, after everything else is "set in concrete".

There are many alternative methods of handling and disposing of sludge materials from wastewater treatment plants. No single system is capable of solving all disposal problems. Each disposal method has advantages and disadvantages; each can be made to work well under a given set of local conditions.

For this next iteration, more accurate data would be necessary. In addition, one may wish to consider the economics of replacing existing sludge unit processes. With a computer program this can be relatively easily accomplished. In addition to being able to compare economics between processes it is also possible to determine economics of future changes in costs to unit processes by conducting sensitivity analyses. In other words, what would happen if the cost of power increases, if the cost of chemicals increases, or if emissions standards increase, or if close-in land becomes available and transportation costs dramatically increase? In the last mentioned situation, future unit cost for transportation becomes important and the flexibility of the plant to obtain additional dewatering of the transported sludge becomes critical.

Trade-offs are possible with the use of an integrated computer oriented approach. How much extra will it cost, or save, if one approach is used in anticipation of modifications, sometime in the not too distant future, can be determined by conducting some additional analyses.

The end product is that system composed of various unit processes that will "metamorphosize" the sludge for ultimate disposal at the "optimum cost" [not necessarily the least cost].

However, if the approach is limited to a strict technological and economics exercise, it will not suffice.

The problem of sludge disposal is further complicated not only by increasing volumes, but also by such factors as changing character of sludge from advanced waste treatment processes, reduced land availability in metropolitan areas, increased fuel costs coupled with decreasing fuel reserves, and increased emphasis upon the environmental impact of sludge handling and disposal. These considerations must be superimposed onto the engineering aspects.

The following presentation of alternative approaches to sludge handling and disposal will attempt to indicate the compexities, and the interrelationships of sludge disposal processes and the total environment, as shown in Figure 1 and Table 1.

final methods utilized. In reality, only several systems are usually considered without a rigorous analysis of the impact of other alternatives. This archaic approach is completely inadequate.

With available data or easily obtainable data, it is reasonably simple to develop a matric of analytical

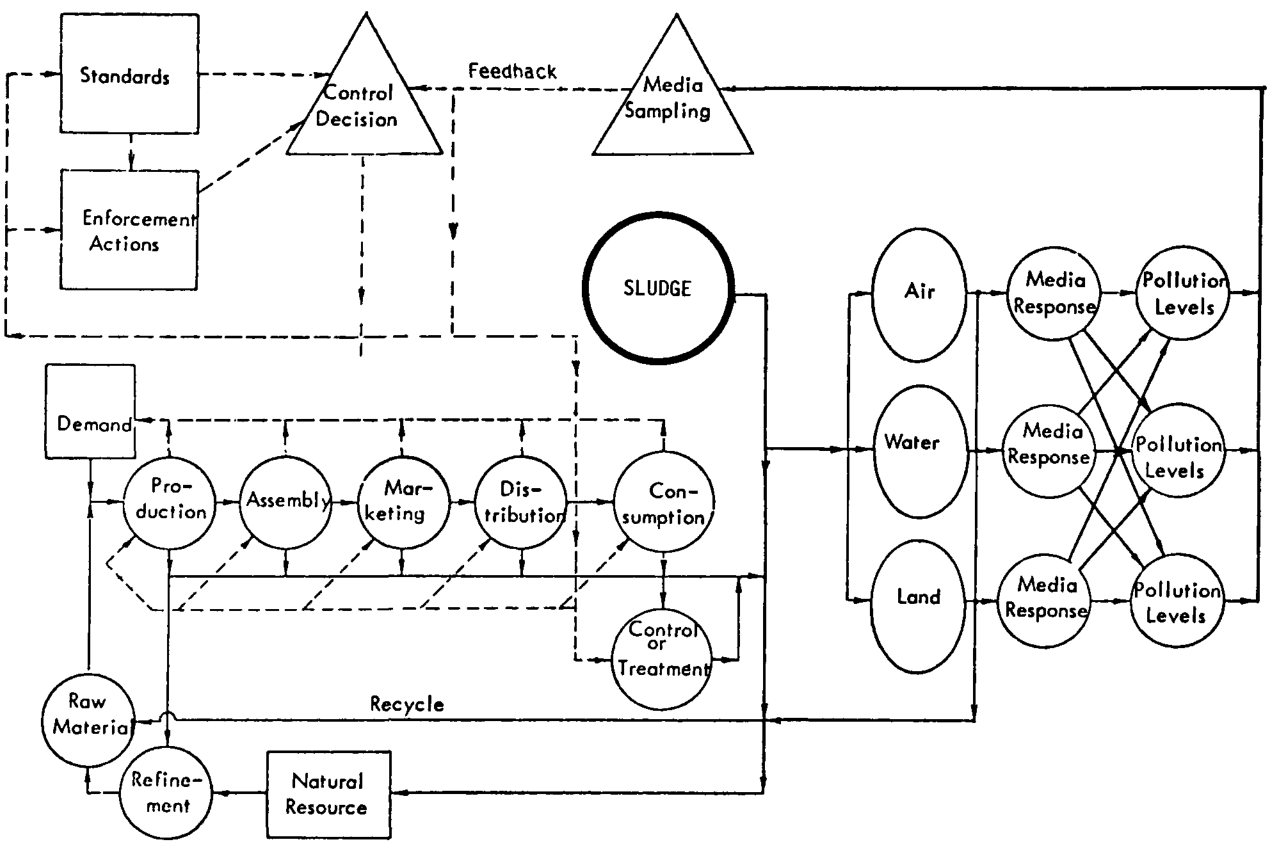

Figure 1: Intermedia Interplay.

Sludge Processing Systems

The general characteristics of the various types of sludges anticipated in BPT and BAT systems were described in Dr. Farrell's paper, "Overview of Sludge Handling and Disposal." Figure 2 represents the alternative processes included in six major sludge handling and disposal unit operations: thickening, conditioning dewatering, incineration, product recovery and ultimate disposal. Table 2 presents the pollutants associated with each unit operation.

The various combinations that can be synthesized to form a system can theoretically be some 44,000. Obviously, consulting engineering companies do not iterate this many times. The effect of current processes weigh heavily on the expressions of costs for each unit operations that should be considered for potential inclusion in a sludge management system. The accuracy of the cost data obtained should be equilibrated to the degree of the iteration and the relative cost of each of the systems synthesized. For example, for the first iteration that may include many variations of sludge handling systems, the cost data that is used may constitute that obtained from the particular treatment plant in question, from company files of past projects and some budget-type data from equipment suppliers. The output from this iteration may reduce the number of candidates from the initial number of let's say 20, to three to six.

The type of information that may be used for this phase may be in the forms shown in Tables 2 and 3.

TABLE 1[1]
Wastewater Treatment Solution Problem Transfer to Other Media (Intermedia Transfer)

Unit Operations	*Organics-Soluble*	*Inorganic-Soluble*	*Organics-Insoluble*	*Inorganic-Insoluble*	*Sulfur Compounds*	*Phosphorus Compounds*	*Nitrogen Compounds*	*Heavy Metals*	*Pathogens*	*Thermal*	*Acidity/Alkalinity*	*Air*	*Water*	*Land*
	WATER POLLUTANTS											*INTERMEDIA TRANSFERS*		
Screening			•	•										Residues[a]
Flotation			•									ODORS		Residues
Coagulation and Sedimentation			•	•		•		•	•			ODORS		Residues
Chemical Addition	•	•	•	•	•	•	•	•			•	ODORS	Compounds formed	Compounds formed
Trickling Filter	•	•	•	•					•					
Activated Sludge	•	•	•	•	•	•	•		•			Aerosols	Residue sludge	Residue Residue & sludge
Lagoons and Stabilization Ponds	•		•	•	•		•					POTENTIAL	Residue Leachate	Residue
Ion Exchange		•			•	•	•	•			•	POTENTIAL		Residue
Activated Carbon	•		•		•		•	•				POTENTIAL	BOD,SS NO_3,heavy metals	
Reverse Osmosis		•			•	•	•	•				POTENTIAL	Residues	Residue
Chlorination									•					
Spray Irrigation	•		•		•	•	•		•			Aerosols	Salt Runoff Leachate	
Ammonia Stripping							•					NH_3	$CaCO_3$	$CaCO_3$
Cooling Towers										•		Heat		

It will not be a simple "economics" approach which will determine the most "effective" sludge management system to be recommended. The most "effective" approach will most likely also include environmental and socio-economic needs that will permit the ultimate disposal of the sludge in a manner that has the least total impact on the quality of the total human-environment complex that is determined for each problem area by the various participants involved. Each sludge management concept incurs assessment and cost analysis.

Therefore, before the delineation of the technology unit costs, and system costs for the various alternative sludge management concepts, environmental and socio-economic factors should be enumerated and superimposed. These factors will have positive or negative impacts in the various technological methods considered and may require modification of the sludge handling concepts to more environmentally acceptable systems.

The following socio-economic-environment considerations will affect the total costs of sludge management:

Energy	Surface Water Quality
Air Pollution	Nitrogen Impact
Health	Soil Pollution
Land Use	Cropping Practices
Resource Recovery	Economic Impact
Public Attitudes	Social Requirements
Secondary Impacts	Ecological Impacts

The relationship between sludge management and these environmental facets is shown in Figure 3

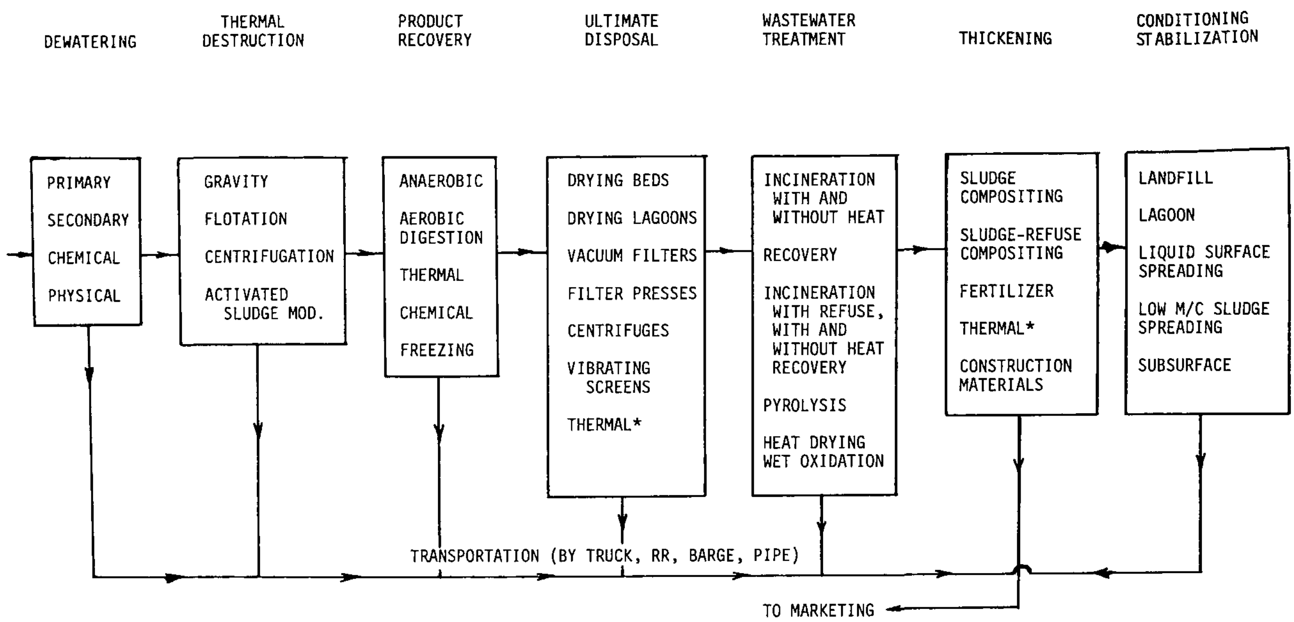

Figure 2: Alternative Solids Handling Processes and Systems.

TABLE 2[1]
Wastewater Treatment Costs

		Model Regression Coefficients			Cost ($) at 1 million gal/day	
Treatment	*Type of Cost*	*A*	*B*	*C*	*Initial Capital*	*Annual Operating*
Oil Separation	CC [a]	4.74702	0.92844	0.22190	55,849	
	OM [b]	0.64345	-0.17671	0.0		15,399
Equalization	CC	4.62325	0.74646	-0.22358	42,000	
	OM	-0.30103	-0.51016	0.06646		1,750
Coagulation-	CC	5.52401	0.61843	0.00842	334,202	
Sedimentation	OM	0.86923	-0.11755	0.00586		25,899
Neutralization	CC	4.69897	0.98569	-0.52716	50,000	
	OM	0.24304	-0.10083	0.0		6,125
Flotation	CC	4.59106	0.44964	-0.02748	38,999	
	OM	0.64345	-0.17671	0.0		15,399
Sedimentation	CC	5.45089	0.55368	0.0	282,416	
	OM	0.64345	-0.17671	0.0		15,399
Aeration	CC	4.54407	0.23408	0.0	35,000	
	OM	-0.30103	-0.51016	0.06646		1,750
Biological	CC	5.07555	0.64300	0.0	119,000	
Oxidation	OM	0.09934	-0.36057	0.07879		4,399
Chlorination	CC	4.17609	0.66317	0.0	14,999	
	OM	0.24304	-0.10083	0.0		6,125
Evaporation	CC	6.11227	1.00000	0.0	1,295,000	
	OM	-0.7112	-0.24314	0.0		2,971
Incineration	CC	5.83373	0.64339	0.0	681,914	
	OM	1.57978	-0.37205	0.0		132,998

[a] CC = Capital Cost
[b] OM = Operating and Maintenance cost

TABLE 3[1]
Residue Disposal Cost Ranges

Disposal Method	*Cost Range ($/Ton-Dry Sludge Solids)*
Outfall	3-5
Wet Oxidation	30-50
Barge (to sea)	10-20
Pipeline to Land	5-20
Truck to Land	20-50
Rail to Land	30-100
Drying	30-50
Compost	5-10
Incineration	40-50

Residue Disposal Costs as a Function of Distance to Disposal Site (Dollars/Dry Ton Sludge Solids)

Transportation Method	*Distance to Disposal Site (miles)* 25	100	200	350
Pipeline	28	100	180	280
Tank Truck	40	130	220	390
Rail Cars	101	170	180	200

and are discussed in greater detail in the following text.

For example, sludge includes significant concentrations of heavy metals as shown in Table 4. Two of the alternatives for ultimate disposal are by incineration and disposal in the land.

Incineration

Figure 4 is a self-explanatory description of the impact of particulate emissions on human respiratory functions.

A recent controversey over emissions from incinerators originally proposed for the Blue Plains Plant serving the Washington, D.C. metropolitan area exemplifies the public's concern. The confrontation is between "scientific" public citizens who work and live in the neighborhood of the proposed plant and who feel they will be detrimentally affected by incinerator emissions. Some of the pertinent allegations and counter comments from both EPA and the Utility are reproduced from the Washington Post newspaper feature article on the subject in Figure 5.

Land Disposal

Disposal to the land is not without its problems. Because of the mineral exchange capacity of soil heavy metals tend to accumulate in the upper soil layers rather than leaching through the soil mantle. For instance, zinc, copper and chromium are extremely toxic to corn.

In one study, zinc concentrations of 306 ppm[4] in the sludge, and a duration which simulated a five year application, the soil concentration of 4969 ppm in sand and 1000 ppm in loam, respectively, was noted. Both concentrations stunted corn yield and growth dramatically.

At a concentration of 81 ppm of copper in sandy soils, effect was minimal but at concentrations of 162 ppm, extensive growth depression occurred. A side effect of the lower concentration was to produce symptoms of iron deficiency. Chromium similarly stunted growth, but exhibited greater effects in silt loam than on sandy soils. It decreased iron content of the soil and also reduced the available phosphorous content of the soil and uptake by the plant.

Lead appears to have very little effect in deep rooted plants but does cause damage to shallow rooted plants. However, the form of the lead plays an important role. Nickel, on the other hand, appears to cause symptoms which are similar to those related to calcium deficiencies.

Other heavy metals will have similar effects, more or less. However, besides the metal, the soil type, pH, organic matter and the variety of plant grown will affect the degree of toxicity. It becomes extremely important, therefore, to conduct appropriate tests with a particular sludge, soil type and crop to determine loading rates, management technique, treatment and countermeasures.

Pathogens are also of concern when one considers land disposal of sludges. Among the common pathogens found in these waste materials are the bacterial pathogens Salmonella, Shizella, Mycobacerium, and Vibro comma; the hepatitis viruses, enteroviruses and adenoviruses; and the protozoan, Endomoeba histolytica. Pathogens may survive in sludge treated soils for several months under favorable climatic conditions. Though pathogen die-back is relatively rapid, fecal coliform, an indicator organism, may persist for some five months. Pathogenic organisms are largely screened out near the soil surface and do not leach through the soil profile.

Moreover, the association of pathogen with aerosols produced by spraying of sludges into land

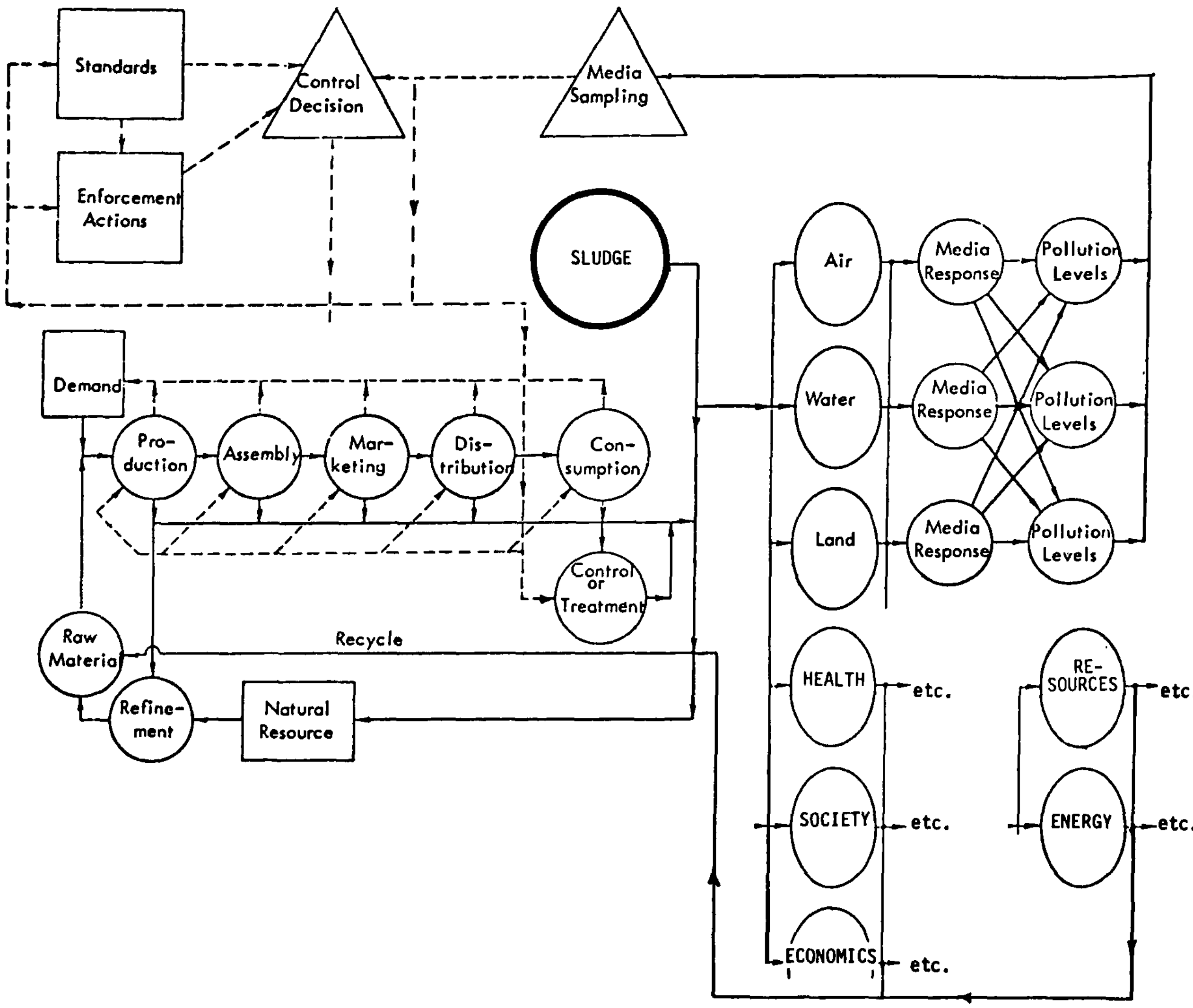

Figure 3: Holistic Residue Intermedia Transfer Flow Chart.

is also of concern. Though pathogens may not be a problem for land disposal, the fact that the literature notes its survival indicates that the land management practices should take this aspect into consideration.

Countermeasures may be as simple as limited public access, use of additional land for buffer zones, limitation of spraying to low wind velocities, and monitoring to assuage public concern.

Resource Recovery

An obvious means for minimizing the cost for sludge management is to produce a product that creates a monetary value. As long as the cost for the additional handling is less than the monetary value received for the product, the cost for sludge management will be decreased. Milwaukee is doing just that with their sale of Milorganite. Lately, another such enterprise has been initiated for the Washington, D.C. market area. Blue Plains sludge will be sold to a private entrepreneur on the basis of a nitrogen assay[5]. The plant now pays $8.25 per wet ton (20 percent solids) to haul the sludge. The plant sludge has a nitrogen assay of 3.5 percent. At this assay, sludge disposal will cost only $8.50 per ton. If the assay increases to 6 percent, sludge disposal will cost only four dollars per wet ton. If methane is produced and sold to the entrepreneur, additional revenues will be received. This would reduce the cost of sludge disposal by $4.25 per wet ton. The company foresees selling the dried product as a 6-4-10 fertilizer for a price of about five dollars for a 50-pound bag. This has obvious marketing limitations as commercial fertilizer provides a much higher nutrient content for that price. The impact of this

TABLE 4[2]
Metals In Sludge
1971-1973

Element	Literature Geometric Mean (ppm)	Literature Spread*	Atomic Absorption Geometric Mean (ppm)
Cd	61	5.89	93
Cu	906	2.66	1840
Hg	14.5	5.24	3.2
Ni	223	4.54	733
Pb	404	4.13	2400
Zn	2420	2.78	6380

*Spread is antilog of standard deviation of log-normal distribution.

commercial venture being successful on the sludge disposal management aspects is likewise obvious.

However, if the goals are met and concept is profitable for the entrepreneur, sludge disposal costs may become as low as one dollar per wet ton.

The recycle of sludges has been practiced for many years[6]. The problems lie with cost for transportation, institutional problems, health oriented problems and public attitudes. Transportation costs for truck, train, and pipe modes of transport and for various distances are shown in Table 3. Institutional problems are associated with nuisance statutes that require certain types of transport containers and routings or preclude certain areas from being considered. Health problems are associated with the viability of pathogens. Public attitudes are such that they can thwart, delay, or also immeasureably increase costs for disposal.

Each of these serve to increase the cost for disposal. Yet each and all of these problem areas must be seriously considered as part of the overall analysis, lest we be led down a road of pseudo-economy.

From the economics point of view, transportation costs vie as the most important, and of these, extraneous moisture as the most significant.

A decrease in water content can save millions of dollars annually. Using the figure noted previously of $8.25 per ton to transport (20 percent solids) sludge some 20 miles from the Blue Plains plant in Washington, D.C. to a U.S. Department of Agriculture site, the annual savings can be approximated as follows:

Daily load = 300 dry tons
Solids content = 20%
Total daily load = 1500 wet tons
Daily cost - $8.25 x 1500 = $12,370
Annual cost = $4,540,000

If, for example, solids content can be increased to 40 percent with heat treatment,

Total daily load = 750 wet tons
Daily cost = $8.25 x 750 = $6,200
Annual cost = $2,260,000
Annual gross savings in transportation costs = $2,180,000

Added to this is the compatability of the product with the environmental health aspects, public attitudes and market value. Detracted from it are the costs and operational problems associated with this particular process.

Other means for resource recovery are:

1. Pyrolysis to produce an activated charcoal which can be recycled to the plant for advanced waste treatment.
2. Heat recovery wherein the sludge is first dewatered to about 40 to 50 percent solids and then burned for its heat value. This can be accomplished directly or mixed with other waste products, coal, or Bunker C fuel oil.

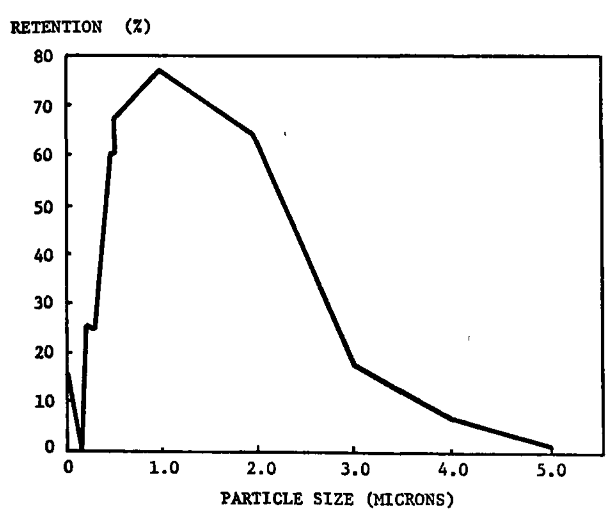

Figure 4: Retention of Particulate Matter in Lung in Relation to Particle Size[3].

Composting

Unfortunately composting requires relatively large areas of land for the composting operations and buffer zone. Most metropolitan sewage treatment plants do not enjoy this luxury. The opposite is usually true. Accordingly, most composting operations require shipment of wet sludge to a re-

They are asking the question because by March, 1975, Blue Plains will be incinerating all the sludge it produces. Sludge is the solid residue of effluent. Present output is 400 tons a day. When the plant is upgraded to advanced treatment, that amount will rise to 2,400 tons daily, or six pounds for every family served by the system.

• The plant will remove pollution from the water and put it into the air: an estimated 1½ million pounds of toxic pollutants will be released into the atmosphere (annually)." (The EPA, using different calculations, puts the amount at 946,000 pounds.)

• The incinerator . . . will release the deadly fumes of oxides of nitrogen and sulfur dioxide which can be converted to highly corrosive nitric and sulfuric acids in the stacks and in the atmosphere, and which can kill in the several tens of parts per million concentration and cause debilitating disease in a few parts per million concentration."

• "The incinerator will put hundreds of thousands of pounds of particulate matter in the air every year: particulate matter containing strongly irritant sulfates and nitrates, silica and highly toxic compounds of mercury, lead, cadmium, arsenic, vanadium, chromium, copper, beryllium and many others."

• The incinerator will . . . contribute several per cent of the average annual air pollution burden of the neighboring counties, and will increase the local air pollution burden near the plant by as much as 100 per cent during the summer months. It will be a grave health hazard."

Based on maximum capacity, incinerator pollutant levels would increase about one-third above EPA estimates,

District sanitation officials said the EPA figures, based on the given average usage, are sound. They said seven incinerators will sometimes reach maximum operating capacity, but at other times they will be operating at much lower capacities.

Figure 5: From *The Washington Post*, March 29, 1973. Feature Article by Thomas Grubisich.

latively distant site, incurring the above mentioned transportation costs. However, a vertical composting operation at the plant site, which would require little precious land space, could be even more attractive than the aforementioned heat treatment.

Export to Foreign Countries

With both the high cost of fertilizer and its scarcity, the value of this by-product of wastewater treatment should increase. The concept is viable for those treatment plants that are available to large vessels such as ore carriers or tankers. Each of these dead head to their points of origin. A load of valuable (albeit) low grade fertilizer would be welcomed, especially to underdeveloped countries that have a poor dollar exchange economy. Because of the size of these shipments, costs per ton should be nominal.

More

Not previously mentioned are the possibilities of modifying the basic wastewater treatment processes to make the sludge more compatible for sludge handling, disposal or sale.

Have you given consideration to even going back into the collection system? We are all aware of the relationship of plant and operating costs to plant size. Regional planning reflects this philosophy.

The following conditions may provide enough incentive to reconsider this "the-larger-the-better" approach:

1. Sludge costs are now 30-50 percent of the total plant operating costs.
2. Future sludge costs will probably constitute a greater percentage of plant operating costs.
3. Environmental, ecological, institutional and public concerns also grow with the size of the daily accumulation of sludge that must be disposed of.
4. Large tracts of land, such as the 40,000 acres used by the Metropolitan Sanitary District of Greater Chicago, may not be as available or will be even more remote incurring high land and transportation costs.
5. Single large plants incur substantial costs for interceptor sewers which become larger and more expensive to supply outlying communities.
6. Disposing of sludge in small quantities from plants located in suburbs have traditionally not incurred either great cost or public obstacles.

Still More

Are these solutions long-term or short-term? Will incinerators, dryers, or heat treatment concepts be able to get fuel? What impact will projected increases in fuel cost have? Are there alternatives or contingency programs that could handle the sludge, if these are the sole handling and disposal methods?

If marketing is an inherent part of the economic flow sheet, what will happen to the market if a significiant number of plants provide similar products in your market area? What will happen if refuse composting also adds to the supply? What is the local, regional, or national market for various similar products?

Will these techniques of sludge management require subsequent laws or regulations to limit the supply or increase the market? For example, should import of peat moss, mulch and other soil amendments into a region be prohibited until all of their fair share of sludge from the sewage treatment plant serving them is consumed within the region supplying the sewage? Will this, then, establish a resource, recovery, and marketing utility?

What will be the impact of 1983 water treatment requirements? Should the 1985 goals of "no discharge" be considered?

How long into the future should we gaze? What long-range guidelines should be established for sewerage authorities to plan their operations and capital investments?

The time is ripe for consulting engineers to consider the *total environmental viewpoint,* one that marries technology to the total environment at a minimum cost.

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THICKENING OF SLUDGES

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ABSTRACT

The extent to which sludges are thickened has a significant influence on the overall cost of sludge treatment and disposal. Yet, rational approaches to the design and operation of thickeners to accomplish an optimal degree of thickening have not traditionally been implemented. The purposes of this paper are to review basic thickening concepts and to illustrate that appreciable cost savings may be realized by avoiding the use of conventional, arbitrary, design loadings for thickeners. Instead, thickeners should be designed to achieve a degree of sludge concentration which, in concert with other sludge treatment processes, minimizes overall sludge treatment and disposal costs.

INTRODUCTION

Thickening inevitably is involved in all schemes for treatment and disposal of sludges. Often, separate thickeners are used to reduce the volume of sludge contributed by wastewater treatment processes prior to subsequent sludge treatment and disposal. However, even if a separate thickener is not provided, thickening is still involved in sludge treatment and disposal schemes. This is because facilities which separate solids from the wastewater treatment process and divert them to sludge handling and disposal facilities normally involve use of sedimentation basins. Such basins serve to clarify wastewater prior to discharge and, indeed, frequently bear the name "clarifier." In addition to accomplishing clarification, these sedimentation basins also are expected to concentrate or "thicken" the solids separated from the wastewater. The concepts of thickening discussed in this paper relate as much to the thickening function of sedimentation basins as to thickening occurring in separate sludge thickeners. In either case, clarification also is going on and must be considered in the design.

In spite of the frequent use of separate thickeners in sludge treatment and disposal schemes, as well as the more common occurrence of thickening within sedimentation basins, the design and operation of such facilities has not usually been accomplished on a rational basis. Thickeners ordinarily have been designed using arbitrary design standards with a little consideration being given to the performance which should be anticipated or to the possible benefits of constructing a thickener of different size. Also, in design, the interaction of thickeners with other treatment and disposal processes has not been rationally evaluated. Yet, because the performance of thickeners influences the performance of other processes, some optimal degree of thickening must be appropriate for each particular sludge and sludge treatment and disposal scheme. Similarly, those charged with the operation of thickeners usually have not explored, on a rational basis, the manner in which their facilities should be operated to make optimal use of the installed thickener capacity.

The technology for making rational assessments in the design and operation of thickeners would seem to be available. The purpose of this paper is to review those concepts and to show their utility in design and operation of wastewater treatment facilities. To do this, thickening theory will be briefly reviewed, the interactions of thickening with other sludge treatment and disposal processes will be discussed, and the economic implications of these interactions will be illustrated.

The Rational Analysis of Thickener Performance

Rational bases for design of thickeners and for analyzing the performance of existing thickeners have been presented[3] and reviewed[2,4] elsewhere and the concepts will only be capsulized here. The following discussion is oriented to gravity thickeners, but is applicable to flotation thickeners by substituting the rate for the settling velocity and reversing the direction of the movement of tank content due to sludge removal.

The basic concept in thickener design is to provide sufficient area so that the solids loading per unit area per unit time (the applied flux, ordinarily expressed as lb/sq ft/day) does not exceed the rate at which solids can reach the bottom of the gravity thickener (or top of the flotation thickener). The rate at which solids can reach the bottom of a thickener depends on the rate at which they settle under the influence of gravity and the rate at which they are transported through the thickener due to removal of thickened sludge. That is

$$G_i = c_i v_i + c_i u \quad (1)$$

where G_i is the possible flux of solids through a layer of concentration c_i; v_i is the gravity settling velocity of the sludge solids at concentration c_i; and u is the bulk downward velocity in the thickener produced by the removal of sludge from the bottom of the tank. Equation 1 is an expression of the possible rate of solids transport per unit area for any concentration in a continuous thickener (one from which thickened sludge is continuously withdrawn). Batch thickeners are a special case in which the $c_i u$ term in Equation 1 is zero.

It should be noted that the $c_i v_i$ term in Equation 1 depends only on the physical properties on the sludge and is not susceptible to control by the designer or operator of the thickener unless physical, biological, or chemical alteration of sludge solids (as by use of a polyelectrolyte) is practiced. In contrast, the magnitude of the $c_i u$ term in the equation depends on the rate at which thickened sludge is removed from the bottom of the tank, and is therefore susceptible to control by the thickener designer and operator.

For optimal performance of a thickener, sludge removal equipment must be designed to uniformly collect thickened sludge from the bottom of the tank so that

$$u = Q_u/A \quad (2)$$

where Q_u is the volumetric rate of removal of thickened sludge from a continuous thickener of area A. Thus, it is seen that the capacity of a thickener for receiving sludge solids can be increased by increasing the rate of removal of thickened sludge. While this may be a desirable course of action for an overloaded thickener, it conflicts with the basic goal of thickening—the production of a concentrated thickening underflow. This is because

$$Q_u = c_f Q_f / c_u \quad (3)$$

and it is desired to maximize the underflow concentration, c_u. Equation 3 was obtained from a mass balance on a thickener receiving feed sludge at a volumetric flow rate, Q_f, with a suspended solids concentration, c_f, assuming that the clarified effluent from the thickener was essentially free of suspended solids.

If the relationship between settling velocity, v_i, and concentration, c_i, is known (see Reference 2 for procedures and difficulties in determining the settleability of sludges), and if a value of u is selected, then the value of the batch flux and underflow flux in Equation 1 can be determined for each possible concentration of sludge which might exist in a thickener.

Figure 1 illustrates the variation of these two terms in Equation 1 with suspended solids concentration and shows the resulting total flux, G_i, possible for each concentration of sludge which might exist in a thickener. It is seen that, in the higher range of concentrations which typically exist in thickeners the value of G_i passes through a minimum. It is this limiting capacity for transmitting solids to the bottom of a thickener, G_L, which limits the capacity of thickeners. Thus, one must ascertain that solids are not applied at a rate greater than G_L, or

$$A = c_f Q_f / G_L \quad (4)$$

It should be noted that, because u, the underflow velocity, is controlled by the designer or operator of a thickener, the value of G_L is controllable. Thus, for a thickener receiving a given solids load ($c_f Q_f$), the value of G_L in Equation 4 can be varied to give any desired thickener area. However, from Equation 1, it can be seen that if a high value of G_L is selected, a high value of u, the underflow velocity, must also be used. From Equations 2 and 3, it is seen that the use of a high underflow velocity would result in the removal of dilute sludge from the thickener. When a new thickener is being designed,

TOTAL FLUX = TRANSPORT DUE TO SEDIMENTATION + TRANSPORT DUE TO SLUDGE REMOVAL

$$G_i = c_i v_i + c_i \frac{Q_u}{A}$$

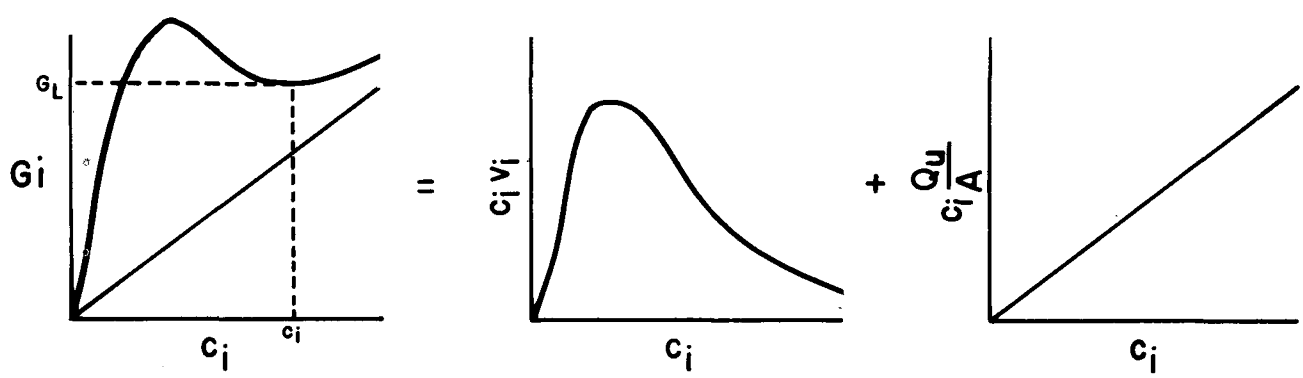

Figure 1: Determination of Allowable Loading on a Thickener.

area, and thus underflow velocity, are unknown. Thus, the solution outlined above becomes a laborious trial and error situation. This difficulty can be circumvented by use of a graphical solution[2]. This simplified procedure is highly recommended for design and routine analysis of the performance of existing thickeners.

Interaction of Thickening with Other Sludge Treatment and Disposal Processes

To illustrate the influence of gravity thickening of the economics of sludge treatment and disposal, the cost of thickening a typical municipal sludge to various concentrations was compared with the savings resulting from the improved thickening in the cost of various sludge treatment techniques. To illustrate the effect of the size of the waste treatment facility on the economics of thickening, calculations were conducted for cities of 10,000, 100,000, and 1,000,000 people.

Sludge Quantities

The following equation was developed to estimate the quantities of sludge to be treated by the various sized cities:

Production of Sludge = suspended solids removed in primary clarifier

\+ nonbiodegradable volatile solids in raw waste which become incorporated in activated sludge

\+ nonvolatile suspended solids carried into activated sludge process

\+ synthesis of activated sludge solids

\+ any organic precipitates formed during biological treatment

−	autooxidation of biological solids
−	suspended solids lost in effluent

This equation may be written as

$$S - [p_{SS}c_{SS} + fh(1-p_{SS})c_{SS} + (1-h)(1-p_{SS})c_{SS} + a(1-p_{BOD})c_{BOD}m_{BOD} + c_p \quad b\frac{(1-p_{BOD})c_{BOD}m_{BOD}}{L} - c_{Se}]Q \qquad (5)$$

The meaning of symbols in Equation 5 is indicated below along with dimensions.

a = amount of biological synthesis per unit of BOD removed, M suspended solids/M BOD (0.5).

b = fraction of mixed liquor volatile suspended solids which are autooxidized daily, dimensionless, (0.12).

c_{BOD} concentration of BOD in raw waste, M/L^3, (178 mg/l).

c_p = concentration of inorganic precipitants formed during biological treatment, M/L^3, (0 mg/l).

c_{Se} = concentration of suspended solids in effluent from treatment plant, M/L^3, (15 mg/l).

c_{SS} = concentration of suspended solids in raw waste, M/L^3, (205 mg/l).

f = fraction of volatile suspended solids entering aeration tank which are not biologically oxidized, dimensionless, (0.35).

h = fraction of suspended solids entering aeration tank which are volatile, dimensionless, (0.75).

L organic loading intensity in activated sludge process, M BOD removed/M volatile suspended solids in aeration tank, (0.4).

m_{BOD} - fraction of BOD entering the secondary process which is removed (based on filtered effluent sample), dimensionless, (0.90).

p_{BOD} = fraction of BOD removed in primary settling tank, dimensionless, (0.33).

p_{SS} = fraction of suspended solids removed in primary settling tank, dimensionless, (0.6).

Q = wastewater flow rate, L^3/T, (at 135 gpcd).

S daily production of waste sludge solids, M/T.

Equation 5 is a modification of Eckenfelder's Equation 11.3[6] with the addition of terms to account for primary sludge, any organic solids precipitated in the biological reactor[9], incorporation of non-volatile solids contained in the raw waste into activated sludge, and the loss of solids over the final sedimentation tank weir. Values of the various constants as assumed for purposes of this illustration are indicated in parentheses in the preceding list. All of these values are subject to variation from waste to waste and none are necessarily applicable to any particular plant. In the absence of information on the amount of inorganic precipitants formed during biological treatment, this contribution toward sludge production was ignored. A waste flow rate of 135 gpcd, a per capita suspended solids loading of 0.23 lb/day, and a per capita BOD contribution of 0.2 lb/day were assumed based on data presented by Loehr[7]. No allowance was made for the probable variation in quality and quantity of waste as a function of the size of the municipality.

Based on the assumed values, sludge production per million gallons of wastewater flow would be 1,425 lb/day of which 1,020 lb/day would be primary sludge, and 405 lb/day would be waste secondary solids. The magnitude of this sludge production is perhaps on the low side of reported experience.

Cost of Gravity Thickening of Sludges

To obtain an indication of current probable costs of thickening and to achieve a basis for illustrating the interaction of thickeners with other processes of sludge handling and disposal, estimates were developed for the cost of thickening sludge to various degrees in municipalities of various sizes. This was done by assuming sludge settling properties (settling velocity as a function of concentration), determining the allowable loading on a thickener to concentrate the sludge to varying degrees, sizing the thickener, and estimating the cost of construction and operation of the thickener of the necessary size.

REQUIRED THICKENER SIZE. As described in an earlier section, the required size of a thickener is a function of the extent to which it is desired to concentrate sludge and of the settling characteristic of the sludge being thickened. In this illustration, the settling properties of a combined primary-secondary sludge were assumed and expressed in the form of an equation used by Dick and Young[5]

$$v_i = a\, c_i^{-n} \qquad (6)$$

where v_i is the settling velocity of sludge at concentration c_i and a and n are constants characterizing the properties of the particular sludge being considered. For purposes of this illustration, a was taken as 0.045 ft/min, and n as 2.57, when v_i is expressed in ft/min and c_i in percent.

The allowable solids loading (the limiting flux) for achieving various degrees of concentration of the sludge were calculated and are shown in Figure 2 along with the resulting required total thickener area for a city of 100,000. Because no differences in sludge production between cities of various sizes was considered, the required thickener areas for achieving various degrees of sludge concentration for cities of 1,000,000 and 10,000 are on an order of magnitude more or less than the values shown in Figure 2.

THICKENER COSTS. In addition to requiring an understanding of factors affecting process performance, optimal integration of sludge treatment processes requires information on the cost of treatment by various techniques as a function of the level of process performance. Unfortunately, rational selection, design, and operation of sludge treatment processes is hampered by a dearth of such cost information. In the case of gravity thickening, such data are in particularly short supply. This is, perhaps, because thickening normally is the cheapest step in sludge treatment and disposal and, thus, thickening costs often tend to be lumped into the cost of other sludge processing techniques. Additionally, sludges vary widely in their thickening characteristics, and unit costs for thickening would be expected to vary accordingly. As with all current cost estimations, inflation also imposes complications. In Burd's review[1] of the state of the art in sludge handling and disposal, it was generalized that separate sludge thickening costs from two to five dollars per ton of dry solids. Smith[13] presented equations for the cost of construction of gravity thickeners as a function of area. In neither case was the thickening cost related to the degree of sludge concentration achieved. That was accomplished here by estimating the cost of the thickeners sized (Figure 2) to give various degrees of sludge concentration.

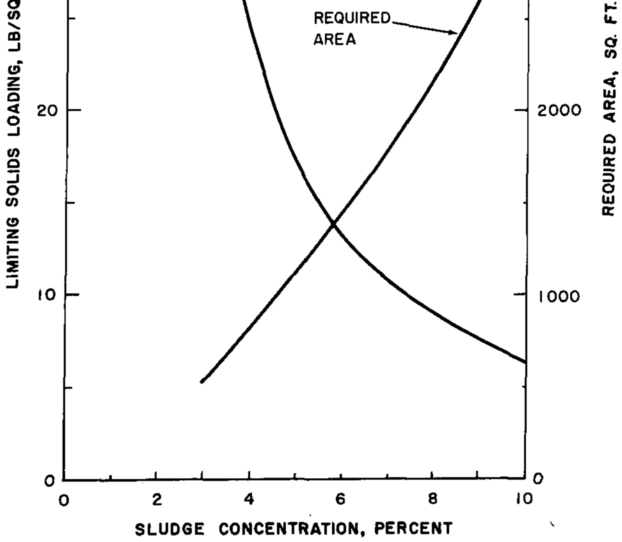

Figure 2: Required Size of Thickeners for Concentrating Hypothetical Sludge to Varying Degrees in City of 100,000 People.

Capital costs for thickeners of various sizes were obtained by adjusting cost data presented by Smith[13] to April, 1974 on the basis of the Engineering News Record Construction Cost Index (the April, 1974 value being 1940) and then increasing the cost by 25 percent to account for contractor's profit, contingencies, and engineering. The resulting capital cost equation was

$$C_{\$} = [54.3 + 26.3\, e^{-A/13400}]\, A \qquad (7)$$

Extensive data on the operation and maintenance of gravity thickeners as a function of their area were not available. In the absence of such information, costs reported by Smith[13] on operation and maintenance costs for primary clarifiers as a function of their area were used. It was reasoned that the equipment and operational requirements were similar to separate thickeners. Arbitrarily, Smith's operational and maintenance costs were adjusted by use of the Engineering News Record Construction Cost Index to make some allowance for changes in costs of labor and materials since his work was published. The resulting equation for an annual operating and maintenance costs as a function of thickener area was

$$OM_{\$} = 2.39A + 189A^{0.5} \qquad (8)$$

To obtain an overall cost of thickening to various degrees, annual costs (operation and maintenance plus amortization of capital costs) were calculated. Then, as shown on Figure 3, costs of thickening to various degrees for various sizes of municipalities

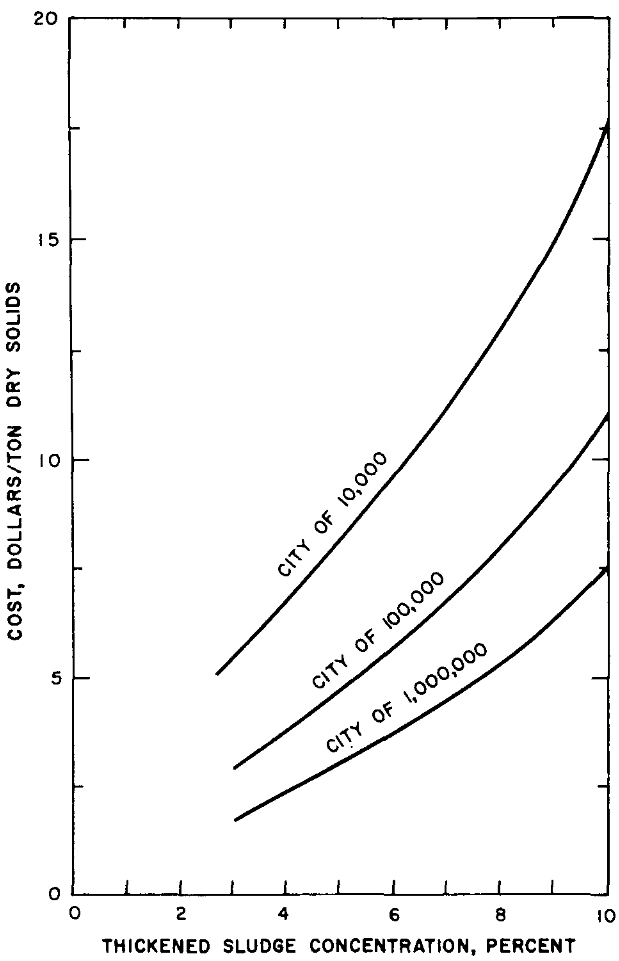

Figure 3: Costs of Thickening Hypothetical Sludge to Varying Degrees.

could be expressed on the basis of total cost per unit of sludge production. For this purpose, the approximate current interest rate on Grade A municipal bonds (6½ percent) was used with a 20-yr amortization period.

Thickening and Dewatering of Raw Sludge

The yield of sludge dewatering devices is increased when water is removed from sludge (as by gravity thickening) prior to being fed to the dewatering device. This is because less water must then be passed through the somewhat impermeable sludge cake in the course of dewatering than would be necessary if the excess water was not removed previously by thickening. Additionally, the degree to which sludge can be mechanically dewatered increases when concentrated sludge is fed to the dewatering equipment[8].

To illustrate the optimal integration of thickening and dewatering processes, the cost of sludge dewatering by vacuum filtration was considered. Then, the total cost of the combination of the thickening and dewatering processes could be evaluated to determine the proper design for each of the two processes.

The effect of feed sludge concentration of filter yield was taken from data presented by Schepman and Cornell[12] which indicated that

$$Y = 0.88c_u \quad 1.0 \qquad (9)$$

where Y is the filter yield in lb dry solids/hr/sq ft, and c_u is the concentration of sludge in the thickener underflow. Extrapolation of the Schepman and Cornell data was necessary to include the range of interests here, but the extrapolated data agreed closely with information on relationship between feed solids concentration and filter yield presented in Quirk[10].

Capital costs for vacuum filters were taken from information presented by Smith[13]. As with the capital costs for thickeners, Smith's estimates were adjusted to the April, 1974 Engineering News Record Construction Cost Index of 1940 and then 25 percent was added for contractors profit, contingencies, and engineering. Capital costs were amortized at 6.5 percent for 20 yr. Costs for labor, power, and maintenance were taken from estimates prepared by Quirk[10] and, arbitrarily, were adjusted to current costs by use of the Engineering News Record Construction Cost Index. Chemical costs for sludge conditioning were taken as $12/ton of dry solids and were not considered to vary with the size of the city or the extent to which the sludge was thickened.

Resulting total costs for thickening and dewatering are shown in Figure 4. The contribution of thickening and vacuum filtration (including conditioning) to the total cost is illustrated for the city of 1,000,000. Total costs curves are shown for all three cities. The relative contribution for thickening and dewatering to the total cost for cities of 10,000 and 100,000 people can be obtained by comparing Figures 3 and 4.

It is seen from Figure 4 that the optimal degree to which the sludge considered here should be thickened for this city of 10,000 people of about 8 percent. For the two larger cities, a total cost became relatively insensitive to the degree of thickening at a concentration of around 8 percent, but a true optimum was not reached within the range of concentrations considered. While the thickening costs involved in reaching these high concentrations are in excess of the costs normally considered for thickening, results would suggest that, with this sludge and these estimates of capital and operating costs, more money should be spent for thickening than is normal practice. However,

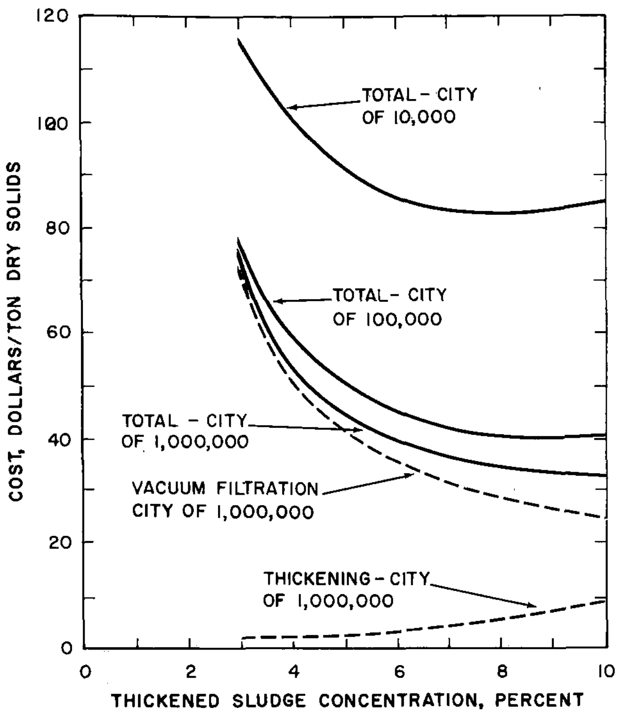

Figure 4: Optimal Integration of Thickening and Dewatering.

because sludge properties vary from plant to plant, the more important point is that great savings in the combined cost of thickening and dewatering is possible by use of a rational approach to design of sludge treatment systems.

Overall Costs of Thickening and Transporting Sludge by Truck

To illustrate the effect of thickening on another phase of sludge handling, overall costs of thickening and subsequent trucking were evaluated for thickeners designed to achieve varying degrees of sludge concentration. For this purpose, trucking costs were taken from estimates prepared by Riddell and Cormack[11] for trucking sludge a distance of 25 miles. Riddell and Cormack's data (which were developed for sludge at 3.5 percent concentration) were adjusted to evaluate the cost of transporting different volumes of sludge containing the same total amount of dry solids. Figures then were adjusted for inflated labor and materials costs by use of the Engineering News Record Construction Cost Index.

Total overall costs for thickening and transporting sludge 25 miles by truck for various sized cities are illustrated in Figure 5. Again, the breakdown of costs is shown only for the city of 1,000,000 people, but the relative contributions of trucking and thickening for the cities of 100,000 and 10,000 people can be obtained by comparing Figures 3 and 5. As before, a true optimum was not achieved within the range of sludge concentrations considered. That is, even though sludge thickening became far more expensive than usual, the incremental cost was justified by the reduction in the cost of transporting the sludge.

SUMMARY AND CONCLUSIONS

Thickening is involved in all schemes of sludge treatment and disposal. If a separate gravity or flotation thickener is not used, then thickening still is involved because it occurs in the sedimentation tanks which produce the sludge. Thickening has a great influence on the cost of sludge treatment and disposal because the cost effectiveness of sludge treatment and disposal techniques depends on the concentration of solids in the sludge.

Traditionally, thickeners have been sized in an arbitrary fashion without regard to the thickening properties of the sludge being treated or to the degree of thickening desired. Yet the size of a thickener does effect the amount of thickening achieved and this effect can be estimated if the settling characteristics of the sludge are known. This allows thickeners to be designed and operated to achieve any desired degree of sludge concentration. The degree to which sludge should be concentrated in a thickener depends on factors such as the nature of the sludge, the size of the community,

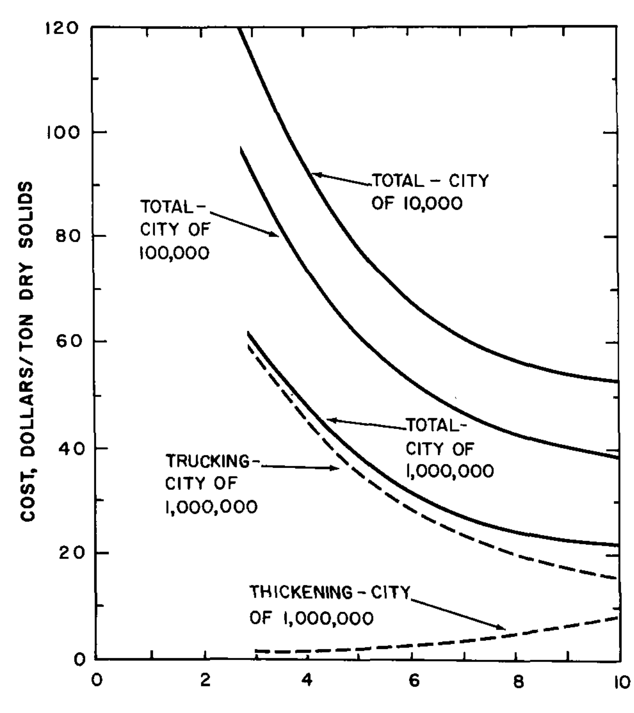

Figure 5: Optimal Integration of Thickening and Trucking.

and the types of other sludge treatment and disposal processes involved in the system.

The effect of designing thickeners to accomplish varying degrees of solids concentration on sludge treatment and disposal costs was illustrated herein. Integration of the design of thickeners with the design of other processes offers significant potential for reducing costs. While this approach to the design of sludge treatment and disposal facilities requires appreciably more information about sludge treatability than normally is available, the results suggest that the potential cost savings warrant the cost of conducting the special studies required.

ACKNOWLEDGMENTS

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ANAEROBIC DIGESTER OPERATION AT THE METROPOLITAN SANITARY DISTRICTS OF GREATER CHICAGO

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ABSTRACT

The practice of anaerobic sludge digestion by the Metropolitan Sanitary District of Greater Chicago is summarized. Topics discussed include capacities of five digestion facilities, digester construction costs, operation and maintenance costs, sludge conditioning and digester flow regimes, heat transfer, loading intensity, gas production, digested sludge characteristics, sludge disposal, digester problems and future improvements in digester operation.

INTRODUCTION

The Metropolitan Sanitary District of Greater Chicago provides wastewater collection and treatment service for Cook County, Illinois. It operates three major plants, three small plants and is completing the construction of a mid-sized advanced wastewater treatment facility. The District's 1973 average daily flow was 1,420 MGD which yielded over 800 tons of solids per day to be processed and disposed.

Each of the three major treatment works, designed to treat 250, 350 and 1,200 MGD respectively, provide conventional activated sludge treatment. While the 250 and 1,200 MGD plants utilize high rate anaerobic digestion, sludge from the 350 MGD plant is pipelined to the 1,200 MGD plant for processing. Anaerobic digestion, however, is not the only type of solids processing facility at the 1,200 MGD plant. Digestion is complemented by two additional solids processing units namely, the heat drying and the Imhoff digestion-drying processes.

Two of the three small plants (6 MGD, 3 MGD and 1 MGD) include high rate digester. However, substantial amounts of undeveloped acreage in the service areas of these plants result in reduced digester loading rates. High rate digestion is also the mode of operation designated for the 30 MGD advanced wastewater treatment plant now under construction.

Digestion Capacity in the District

A spectrum of capacities are included among the digestion facilities operated by the District. These statistics are summarized in Table 1. Although the District's digestion facilities are rated according to tons of dry solids processed per day, TPD, the accompanying plant size is listed in column one for perspective. As noted above the 1,200 MGD plant utilizes other means for processing solids besides digestion. Column 3, which lists the mass ratio of waste activated to primary sludge, was included to define the feed sludge blend.

Three plants have identical digesters. Each 2.5 million gallon unit has a 110 feet diameter, 33 feet wall water depth plus a 1:6 sloped conical floor. Digester volumes are proportionally smaller at the 6 MGD and 1 MGD plants. All existing digesters are equipped with floating covers, however, fixed cover units have been considered in future expansion planning. Moreover, the District's digesters are operated as single stage processes except for the 0.3 ton/day facility. The detention time listed is the average for 1973, however, the design average detention time at the end of the design period is 14 days for each facility.

TABLE 1
Digester and Plant Sizes

Plant (MGD)	*TPD (Ton/Day)*	*Act:Pri Ratio*	*Volume (MG)*	*No. Units*	*Detention Time (Days)*
1,200	*425	75:25	2.5	12	14
250	120	65:35	2.5	8	20
**30	70	85:15	2.5	4	18
6	4	65:35	0.18	4	30
1	0.3	55:45	0.09	2	60

*Additional solids to other processes.
**Under construction.

Capital Costs

Capital costs for six District digester construction projects are tabulated in Table 2. The actual contract bid price was updated to December 1973 levels using the ENR Construction Cost Index of 1939.0. Cost comparisons in terms of present dollar value can be made. Note that the cost for Construction Stage III at the 425 TPD facility includes the cost of four digesters plus four thickeners. These flotation thickeners are physically identical to those built six years earlier in Construction Stage II. As a result the cost comparison between Stage III, and Stages I plus II is within three and one-half percent. Furthermore digesters built in Stages I and II at the 120 TPD facility and those built in Stages I and II at the 425 TPD facility are also physically identical. The adjusted costs confirm the similarities. Finally, the comparative cost increase in Stage IV can be explained by the additional digester appurtenances included in the contract. Additional sludge recirculation pumps, sludge transfer pumps, piping interconnections, remote controlled valve operators and instrumentation were provided in the Construction Stage IV contract. Moreover an estimated five percent of the cost was directed toward updating the 8 digesters built in 1962 or 1968. The time lag in construction can be placed in perspective by noting that the Stage IV contract was bid in November 1971 but the digesters were not placed on line until January 1974. Construction costs for the 70, 4 and 0.3 TPD facilities were not available. These digesters were built when the plants were initially constructed. Since the costs for the various processes in the plant were not individually itemized in the bid price, accurate estimates of digester costs could not be made.

Operating and Maintenance Manpower

Several personnel classifications are involved in operating the District's digesters. Table 3 lists the types of manpower and the number of manhours per week directly chargeable to digester operation. Technical supervision, indirect operating manpower involved in sludge conditioning and disposal processes and digester maintenance manpower are not included. However, technical and plant supervisory costs allocated to digestion have been estimated at 21 percent of the direct operating salary costs. The maintenance manhours average approximately 25 percent of the operating manhours. The data in Table 3 demonstrate the

TABLE 2
Digester Construction Costs

TPD (Ton/Day)	*Construction Stage*	*Description*	*Year Bid*	*Cost* Millions of $*
425	I	4 Digesters	1962	3.10
	II	4 Thickeners	1962	2.36
	III	4 Digesters & Thickeners	1968	5.27
	IV	4 Digesters	1971	4.14
120	I	4 Digesters	1962	2.49
	II	4 Digesters	1967	2.93

*Based on December 1973 ENR Construction Cost Index = 1939.0.

TABLE 3
Operating and Maintenance Manpower

TPD (Ton/Day)	*Man Hours Per Week* Operating Engineers	TPO	Laborer	Fireman-Oiler
425	200	0	480	40
120	200	40	200	80
*70				--
4	0	66	4	0
0.3	0	7	0	0

Supervisory Approx. 21 percent of Direct Operating Dollars.
Maintenance Approx. 25 percent of Operating Man Hours.
Base Labor Wage $5.95.
*Under Construction.

"economies of scale" that accrue with increasing capacities of the District's digestion facilities.

Conditioning and Flow Regime

As a general rule it is inefficient to discharge waste activated sludge and primary sludges directly into a digester. These sludges, especially the waste activated, are too dilute and should be concentrated. Table 4 lists the types of sludge conditioning practiced by the District. Current practice ranges from gravity thickening at the 0.3 TPD facility to a combination of screening, gravity thickening, vacuum filtration, cake dilution and sludge grinding at the 425 TPD digestion complex. Flotation thickening of activated sludge, aided by additional chemical flocculants is also practiced.

At the present time none of the District's digesters are operated as continuous flow reactors. Although it is recognized that continuous flow is desirable to minimize shock loading and smooth the rate of gas production, hardware limitations to date have prevented the District from implementing this regime. Continuous feed may be implemented at the large digestion facilities but smaller plants, because of limited availability of operator time, will continue to be fed and drawn on an intermittent schedule. Reliable meters, level sensors, valve status indicators, pump speed controllers, timers and remote control equipment can be used to automate continuous flow operation, however, quality equipment and a planned maintenance program are essential.

Mixing

Mixing is practiced at all District digestion facilities. Designed into each digestion project is the capability for continuous pumped recirculation of the digester volume at least once in 24 hours. Design practice also calls for pump and valving flexibility to permit either recirculating the digester contents through external heat exchangers or around them. Besides pumped sludge recirculation the District has also provided gas recirculation on most digesters. This form of mixing has not achieved its full potential since the particulate and aerosol laden digester gas fouls the compressors employed to recirulate the gas. Hydrogen sulfide

TABLE 4
Conditioning and Flow Regime

TPD (Ton/Day)	*Conditioning*	*Feed Schedule*	*Mixing*
425	Screening, Gravity Thickening, Blending With Vacuum Filter Cake, Grinding	Once Per Shift	Pumped Recirculation
120	Gravity Thickening And Screening	Semi-Continuously	Pumped Recirculation
*70	Flotation Thickening	Computer Controlled On Day Shift	Gas & Pumped Recirculation
4	Flotation Thickening of Activated, Gravity Thickening of Primary	Feed On Timed Cycle - Draw 3 - 5 Times/Week	Gas & Pumped Recirculation
0.3	Gravity Thickening	Feed 3 Times/Week Draw 2 3 Times/Week	Gas & Pumped Recirculation

*Under Construction.

TABLE 5
Heat Transfer

TPD Tons/Day)	*Heat Exchanger*	*Area (Ft.²)*	*Temp. Range Raw Sludge (°F)*	*% Solids*	**BTU/Ton Dry Solids (in Millions)*
425	External With Hot Water	9,200	60 - 70	4.8	1.04
120	External With Hot Water	4,000	52 72	2.9	1.72
**70	Jacketed Draft Tubes			4.0	1.20
4	External With Hot Water	112	55 72	3.9	1.23
0.3	External With Hot Water	50	53 73	3.5	1.37

*Based On Raising Raw Sludge Temperature From 70 to 95° F.
**Under Construction.

corrosion on the other hand has not been a problem with District digesters.

Heat Transfer

Four of the five digestion facilities listed in Table 5 utilize external, hot water heat exchangers. This equipment is readily accessible for service and has performed satisfactorily for about ten years at several facilities. The exchanger tubes become coated with residues from sludge and must be rejuvenated on a two to five year basis. Table 5 lists the total transfer surface area at each facility rather than the manufactures BTU transfer rate since the transfer rate substantially declines within a few months after startup. Ninety-five degrees Fahrenheit is the nominal set point for digester sludge with a weekly difference between minimum and maximum temperatures being less than five degrees. The range of monthly average raw sludge temperatures for 1973 are also presented.

Column 6 lists the theoretical BTU requirements for heating the sludge, having the percent solids concentration defined in column 2, from 70 to 95° F. In order to illustrate the value of thickening raw sludge prior to digestion, the BTU requirements are expressed on a per dry ton of solids basis. Note that the 2.9 percent solids sludge at the 120 TPD facility theoretically requires approximately 70 percent more BTU's than the 4.8 percent solids sludge at the 425 TPD facility. A different type of heat transfer equipment is being provided at the 70 TPD facility now under construction. Digester sludge will be heated by six jacketed draft tubes inserted through the digester cover into the sludge mass. A single external boiler serving the four digester complex will circulate hot water through the jacket of each draft tube. Performance data on this type of equipment will not be available until the plant is placed in service.

Loading Intensity

Besides a minimum design residence time of approximately ten days another limiting design parameter for digesters is organic loading rate. Organic loading rate (OLR) is defined as the pounds of volatile solids fed for each cubic foot of digester volume per day. A well operated high rate digester is normally fed at a rate between 0.1 to 0.3 pounds of volatile solids per cubic foot per day. Table 6 lists the range of 1973 monthly average organic loading rates (OLR) for the various digestion facilities. Although the 425 TPD facility had an OLR typical of high rates, the District does not intentionally operate its digesters at the lower loading rates, OLR. In fact several of its high rate digesters have been operated at OLR approaching 0.3 with effective hydraulic residence times on the order of ten days. Although these experimental operating conditions were maintained for less than five times the hydraulic time constant or residence time, the digester performed well and produced an effluent sludge quality similar to that yielded at an OLR of 0.15 and hydraulic residence time of 14 days.

TABLE 6
Digester Loading Intensity

TPD (Tons/Day)	*% Solids*	*% Volatile*	*OLR Lb. Vol. Solid Ft³ Day*	*Detention Time (Day)*
425	4.6 - 5.2	61 - 70	0.13 - 0.17	14
120	2.3 4.2	51 - 63	0.045 0.057	20
*70	4.0			18
4	2.4 4.5	63 - 73	0.052 - 0.061	30
0.3	2.5 4.0	55 65	0.036 - 0.043	60

*Under Construction.

TABLE 7
Digester Gas Production

TPD (Tons/Day)	*Gas Production Ft³ Lb. Destroyed*	*(TSCFD)*	*% Utilized*	*CH_4/CO_2*
425	14 17	2500 3800	70 85	1.50 1.75
120	13 19	500 700	80 - 95	N.A.
*70				
4	14 17	12 15	85 - 95	N.A.
0.3	N.A.	N.A.	N.A.	N.A.

*Under Construction.
N.A. Not Analyzed.

It appears feasible to operate the digesters at the higher loading rates, however, there are several reasons why the District has not adopted this practice. Organic loading rate is a function of solids concentration, volatile solids content and hydraulic residence time. Since sludges, which are predominantly composed of waste activated sludge, are difficult to concentrate above four percent solids without employing mechanical dewatering equipment, concentration is therefore a constraint. Furthermore, District sludges are characteristically lower in volatile content than other municipal digester installations. Finally, hydraulic residence time, the easiest variable to manipulate in order to increase or decrease the OLR, has been fixed by District policy at a minimum of 14 days. The District's exploratory studies as well as digester operating records reported in the literature indicate that satisfactory performance can be attained at lower hydraulic residence times. The District however maintains the 14 day minimum as additional assurance to the regulatory agencies as well as the community organizations near the District's Land Reclamation site that the sludge is completely digested.

Gas Production

Rate of digester gas production and gas composition are important process variables in digester operation. These data monitored at the District's facilities are summarized in Table 7. Column two, which lists the cubic feet of digester gas produced per pound of volatile solids destroyed, indicates that the unit production is typical of other municipal digester installations. Columns three and four list the total gas production in thousands of standard cubic per day (TSCFD) at each facility and the percentage utilized for heating the raw sludge feed, maintaining digester temperature and heating the digestion complex buildings. Note that when the total gas production is hundreds of thousands up to several million standard cubic feet per day, a 5 to 30 percent excess is an enormous source of energy. The District is currently investigating various means for capturing this energy for other uses. One potential scheme is steam production for electrical power generation.

Besides maintaining an inventory of the gas produced, the gas composition is monitored at the 425 TPD facility as an indicator of digester stability and performance. The volumetric ratio between methane and carbon dioxide, measured by a gas partitioner, is determined daily on a sample of gas from each digester. Detailed gas analyses have indicated that H_2S, H_2, N_2 and other gases are negligible compared to methane and carbon dioxide. Therefore, a CH_4/CO_2 ratio of 1.50 to 1.75 indicates a methane composition ranging between 60 and 64 percent by volume. As a result typical fuel values of the digester off-gas range from 600 to 650 BTU/ft³ digester gas.

Digested Sludge Characteristics

The quality of digester performance can be gaged by analyzing the final product. Digested sludge characteristics reported at the various District facilities are summarized in Table 8. Columns three and four indicate the reduction in solids and volatile matter respectively. The District, however, does not consider the percentage reduction in volatile solids to be a significant performance variable. This variable is dependent primarily on the volatile content of the feed sludge rather than digester efficiency. The total volatile acids concentration, TVA, listed in column 5 is more indicative of the degree of "complete" digestion since it is the principal intermediate product in the series anaerobic digestion reaction.

An important principle is supported by the TVA data in Table 8. Continuous culture theory indicates that a steady state, the effluent substrate concentration from a completely mixed reactor is

TABLE 8
Digested Sludge Characteristics

TPD (Ton/Day)	OLR Lb. - Vol. Sols. / Ft³ Day		% Solids	% Volatile	TVA (mg/L)	ALK (mg/L)	pH
425	.13	.17	3.5 - 4.2	55 59	50 150	2900 4100	7.0 - 7.3
120	.045	.057	2.1 3.6	45 55	74 228	1700 2800	6.8 7.1
*70							
4	.052	.061	2.3 3.4	51 59	120 260	2100 3000	7.1 7.6
0.3	.037	.043	N.A.	N.A.	N.A.	N.A.	N.A.

*Under Construction.

nearly independent of the influent substrate concentration. The data indicate that the District's digestion facilities support this theory. In spite of the range of influent concentrations represented by the OLR, the final effluent concentrations represented by the TVA values are nearly identical. This indicates that digested sludge quality is not adversely affected by operating at the higher organic loading rates.

Another principal of anaerobic digestion is illustrated in Table 8. Digested sludge alkalinity is more or less proportional to the feed sludge solids concentration. Alkalinity increases due to protein degradation with its subsequent release of ammonia. Ammonia reacts with carbonic acid to produce ammonium bicarbonate. Since the protein concentration is relatively proportional to the solids concentration the resulting alkalinity follows the same proportionality. Note that the alkalinities in Table 8 demonstrate this relationship with the feed solids concentrations listed in column 2 of Table 6.

Methods of Disposal

Sludge disposal is the final step in a sludge management program. The District, in keeping with the concept of recycle and reuse, has adopted a program of land application as its principal means for sludge disposal. Table 9 summarizes the disposal route for each digestion facility.

The District has been involved in refining the technology of land application of sludge solids for several decades. Extensive experimental and pilot studies led to the development of the Prairie Plan which was recognized as the *Outstanding Civil Engineering Achievement of 1974* by the American Society of Civil Engineers. The Prairie Plan is the District's program of reclaiming strip mined land through application of anaerobically digested sludge. It is the 425 TPD digestion facility which serves as the primary source of digested sludge for the Prairie Plan. Solids from the other facilities are recycled on other land application sites in or near the Chicago area.

TABLE 9
Methods of Disposal

TPD (Ton/Day)	Description
425	Barge To Land Reclamation Site, Application, Cropping.
120	Concentration In Basins, Land Application, Cropping
*70	Mechanical Dewatering, Land Application
4	Concentration In Basins, Land Irrigation, Cropping
0.3	Discharge To Interceptor To 120 TPD Plant

*Under Construction.

Problems

Anaerobic sludge digestion, although well suited as a solids processing technique for the District, has encountered problems. Several of these difficulties, accompanied by the steps which the District has taken to overcome them, are summarized below.

Thickening

Because of the large proportion of waste activated sludge in the digester feed, the maximum solids concentrations attainable have been 2.5 to 3.0 percent by gravity thickening and 4.0 to 4.5 percent by flotation thickening using flocculating agents. These appear to be firm upper limits. At the 425 TPD facility high feed sludge solids concentrations are attained by vacuum filtering the waste activated sludge to a 15 percent solids concentration and then diluting the cake to the desired concentration. Theoretically any solids concentration from 3 to 15 percent can be obtained. However, above six percent solids the sludge viscosity exceeds 100,000 centipoise and its rheological properties tend to mimic those of a paste. As a result the target operating range is 5 to 5.5 percent solids.

Clogging

From the outset of digestion experience at the District, clogging of recirculation pumps and reduction of the effective digester volume by rags and tenacious mats of string, hair and fibers was a problem. Current design practice calls for the screening of all digester feed sludges to remove much of this troublesome material. Moreover, sludge grinders are employed at the 425 TPD facility to further insure the homogeneity of the sludge feed. Screening and grinding appear to reduce digester maintenance costs in addition to providing a more uniform feed.

Foaming

Accumulation of foam in the gas space under the floating cover as well as around and over the edge of the floating cover has been a problem. Part of the difficulty is inherent due to the presence of surface active agents among the products of biological decomposition. The problem can be accentuated by undesirable digester feeding practices. If the digester is fed only once or twice a day, the microbial population metabolizes vast amounts of substrate over a short period of time thus producing vigorous gasification. Vigorous gasification in turn results in rapid foam formation. The overall foaming problem can be reduced if the gasification rate is maintained relatively constant by uniform continuous feeding several times per shift. Pumped recirculation of sludge to the gas space under the floating cover can also be employed to mechanically destabilize the foam.

Gas Recirculation

Most District digesters employ gas recirculation for digester mixing. In most instances the moist foam and grease laden "dirty" digester gases tend to foul the recirculation compressors. Fortunately hydrogen sulfide has not been a problem. In order to increase the mean time between compressor failure the District has been considering redesigning and relocating the condensate traps as well as the possibility of gas scrubbing upstream from the gas compressors. Both of these areas appear promising.

Supernatant Separation

One other problem, which is appropriate to mention, has been the slow rate at which supernatant separates from digested sludge. All of the digesters are operated as completely mixed reactors. As a result the well mixed digested sludge, which is supersaturated with carbon dioxide, separates slowly. The buoyant action of the carbon dioxide tends to keep the solids in suspension. Gravity concentration of digested sludge from approximately four to six percent solids requires about one month. This is one of several reasons why the District has not designed "two stage" digestion facilities. The total volume of the second stage reactor would be more than twice the volume of the primary digesters. Although the problem has not been resolved, vacuum degasification of the digested sludge drawoff has shown some potential.

Other minor difficulties have been encountered from time to time. These for the most part have been resolved and the net advantages of anaerobic digestion have made digestion the primary means for sludge processing at the District.

Potential Improvements for the Future

Bench and pilot scale research on sludge digestion has advanced significantly beyond the status of current operating practice. This has created a potential for improvement in field operations. Several improvements which may soon be implemented, not only in Chicago but throughout the country, are the following:

1. Shorter residence times as a result of more homogeneous feed sludges, improved flow regimes and more frequent sludge analysis.
2. Uniform digester feeding and withdrawal accomplished by automatic mass balance control.
3. On-line measurement of process stability indicators such as the rate of *methane* production.
4. Digester gas scrubbing in order to (a) produce a cleaner fuel of higher BTU value; (b) reduce gas recirculation compressor fouling; (c) provide pH control by removing the weak acid, carbonic acid, rather than adding a base.

This list is by no means complete and plant operators and process engineers will, without a doubt, implement other improvements. As a result, anaerobic digestion of municipal sludges, with its current advantages, coupled with the potential for significant refinements, should continue to be one of the principal means for sludge processing.

METRO DENVER'S EXPERIENCE WITH LARGE SCALE AEROBIC DIGESTION OF WASTE ACTIVATED SLUDGE

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ABSTRACT

Metro Denver in 1970 converted excess secondary aerators to aerobic digesters. The plant scale system was compared with a pilot open tank oxygen system using both slot and rotating diffusers. V.S.S. reductions ranged between 11.2 and 47.2 percent for the air system. A significant correlation between V.S.S. reduction and S.R.T. x temperature was observed. Cold shock eliminated nitrification for a five month period. When invertebrates (particularly rotifers) comprised significant fraction of the biomass, digestion was maximal. Supernatant concentration averaged ten percent of anaerobic supernatants. Biodegradable V.S.S. auto-oxidation coefficient k = 0.27 for oxygen batch test. No correlation was observed between D.O. concentration and V.S.S. digestion rates. Temperature differential increased with increasing loadings between ambient and biomass. At loadings > 0.14 pounds V.S.S./ft^3/day, oxygen performance is superior. To continue the economic benefits of reduced sludge disposal costs, Metro is considering conversion of a one million gallon tank to an oxygen aerobic digester with rotary diffusers.

INTRODUCTION

Aerobic digestion may be regarded as modification of the activated sludge process. Figure 1 depicts the relationship of the aerobic digestion process to other activated sludge modifications from "high rate" to "extended aeration" on a time-concentration continuum (Sa•t values in units of hours x mg/l). As the biomass concentration increases, settling velocities decrease, food to microorganism ratios become infinitesimal and net sludge synthesis becomes negative because of auto-oxidation and predation.

The major problem associated with the activated sludge process involves the disposal of excess waste activated sludge. There is, therefore, an obvious economic incentive to aerobically digest as concentrated a sludge as possible. The limiting factor in accomplishing a high rate of solids reduction in a thickened waste activated sludge is oxygen transfer capability. New developments in the field of pure oxygen fine bubble diffusion technology have successfully overcome this limitation.

In 1970 the Metropolitan Denver Sewage Disposal District No. 1 (Metro) embarked upon a two-pronged aerobic digestion program. The first part of the program involved plant scale aerobic digestion of dilute W.A.S. in four converted secondary aeration basins (eight million gallongs). The second part consisted of an extensive research and development program to compare diffused air performance with pure oxygen pilot plant aerobic digestion on a batch feed and continuous feed basis. Preliminary research data indicated that high oxygen transfer efficiencies (> 90 percent) could be achieved by applying a unique fine bubble oxygen diffuser in an open tank system (Marox Systems, F.M.C. Corporation, Englewood, Colorado).

On the basis of the large scale plant experience with aerobic digestion, as well as the open tank oxygenation research efforts, a contract was awarded to Metro in June 1972 by the Environmental Protection Agency for the investigation of diffused air and pure oxygen aerobic digestion of waste activated sludge. The diffused air plant scale phase began on August 1, 1972 and was completed

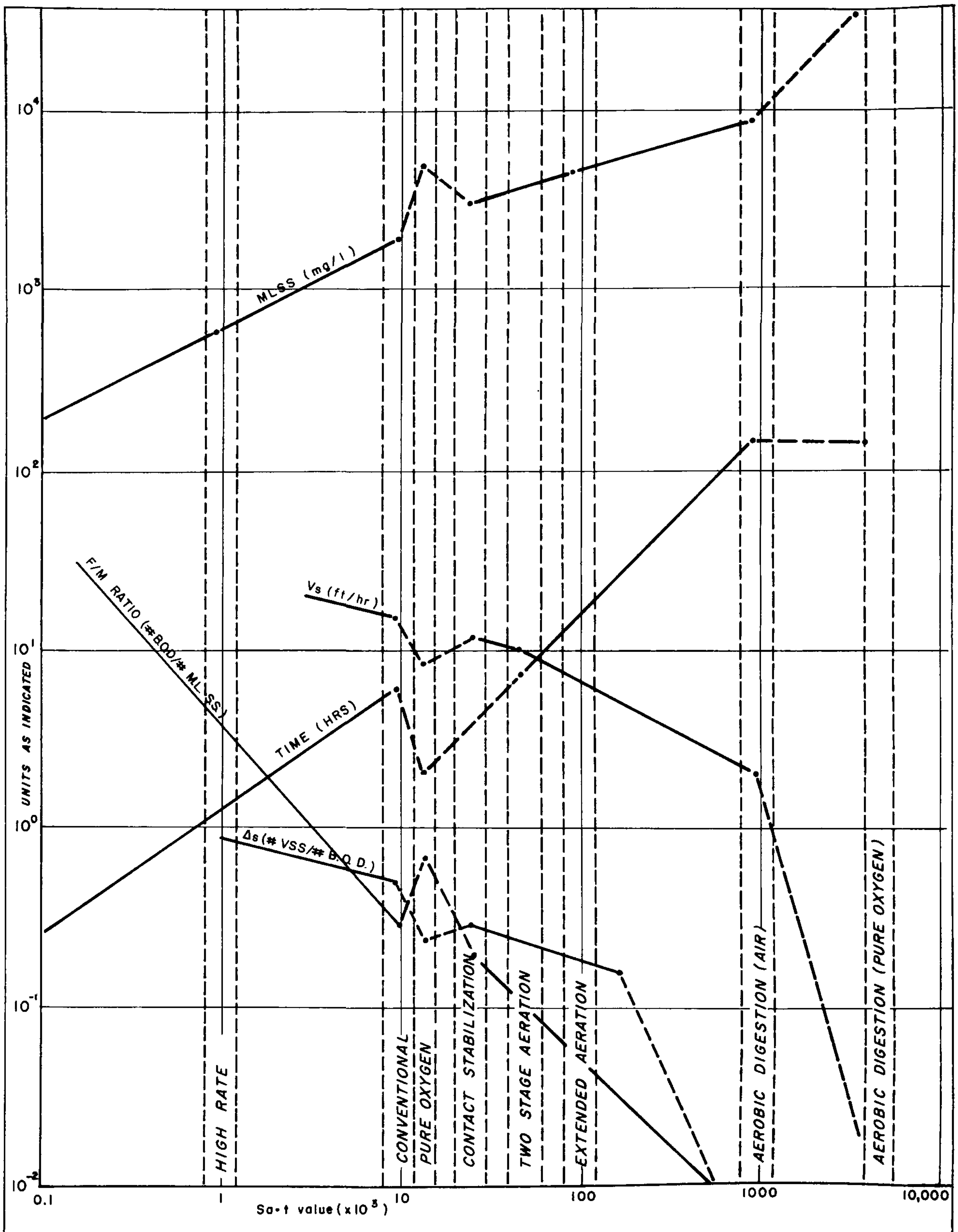

Figure 1: Activated Sludge — Time-Concentration Continuum.

on August 31, 1973. The pure oxygen digestion phase began on November 1, 1972 and continued until April 1974.

Oxygen Pilot Plant Phasing

The first stage of the oxygen investigation included a series of five batch tests for evaluation of diffuser hardware and system performance. The batch tests were run using both fresh as well as diffused air digested concentrated waste activated sludge (three to five percent solids).

The second stage consisted of a continuous feed system in two 1,800 gallon tanks using a slot-type diffuser for determining the effect of varying loading rates on system performance. During the five phases of this stage, the volatile suspended solids loadings ranged from 0.083 to 0.433 pounds V.S.S./ft^3/day.

The third stage replicated the second stage but substituted a rotating diffuser system for the slot diffusers. The loading rates were 0.43 and 0.60 pounds V.S.S./ft^3/day.

Metro Diffused Air System

The plant scale diffused air system was based entirely on existing aeration equipment consisting of fine bubble precision tube diffusers. In this system "fine bubble" is defined as an average bubble diameter of approximately 2 to 5 mm. The only innovation in the plant scale system consisted in the shutting off of diffused air in the third and last pass of the aeration basin once a day for several hours to allow for solids/liquid separation.

Pure Oxygen Diffusion Systems

The pure oxygen slot diffuser requires recirculation of liquid sludge past gas diffusion bars, to provide minute oxygen bubbles (average bubble diameter is 50 to 100 microns). A bubble of 100 microns diameter would require a water depth of four feet to obtain 100 percent dissolution before reaching the air/water interface.

Upon completion of the EPA contract, a new type of gas transfer device developed by F.M.C.-Marox Systems became available. This device called the rotating diffuser employs the same shear principle for small bubble development that is used in the slot type diffuser. Whereas with the slot type diffuser the shear is obtained by recirculation of fluid through a narrow orifice past the gas bars, shear is obtained with the rotating diffuser by revolving a diffuser through the liquid at a speed equivalent to the flow velocity required with the slot diffuser ($\approx$ 20 ft/second). The major advantage of the rotating diffuser is that this device does not require prescreening (Figure 2).

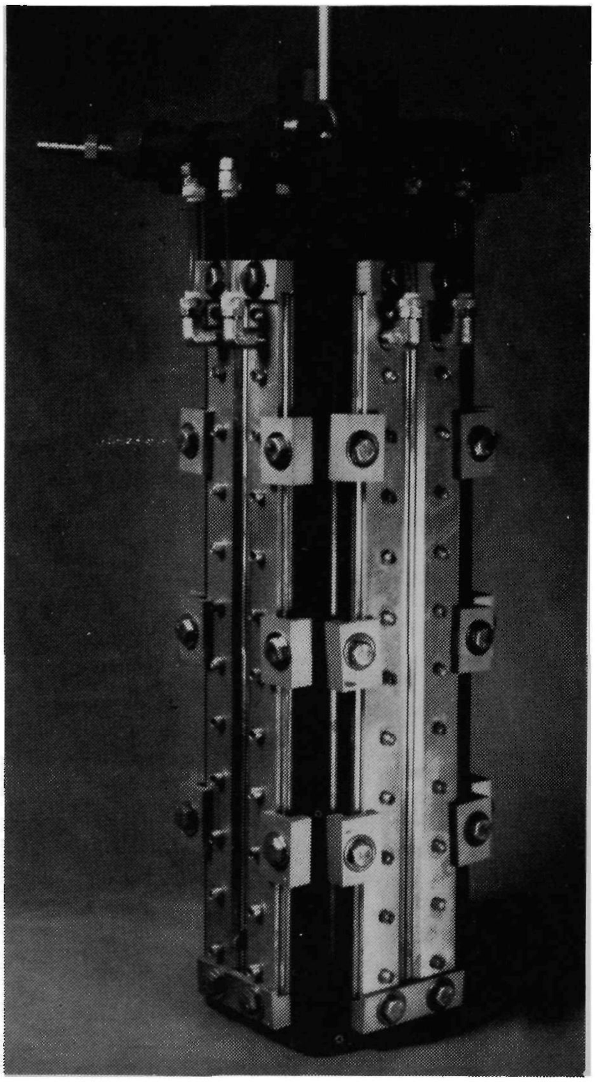

Figure 2: Slot Diffuser.

Scope of the Study

Variables investigated in relation to aerobic stabilization performance included: time of stabilization, volatile solids loading, temperature, oxygen supplied per unit volatile solids reduced, dissolved oxygen concentration, oxygen uptake rates, sludge settleability, supernatant quality, odor levels, dewaterability and physical/chemical and microbiological characteristics.

Experimental Data — Diffused Air System

Table 1 compares the percent change between influent and effluent for various physical/chemical characteristics with variations in sludge retention time.

Considerable confusion exists in the literature with regard to the solids form that is aerobically digested or reduced. Some authors base their calculations on total solids, others use total volatile solids and still others use volatile suspended solids. This study is based on volatile suspended solids (V.S.S.) reduction as the criteria for determining degree of aerobic stabilization. Collodial materials have not been dealt with separately in this analysis and are assumed to be part of the dissolved solids passing through the Gooch filter. It should be noted that although V.S.S. is the criteria used for determining the diffused air system performance, biodegradable V.S.S. is also considered when discussing the pure oxygen batch tests.

coefficients of correlation were calculated for several environmental-operational functions within the asymptotic limits previously observed, the most significant correlation (r = + 0.93) was observed between V.S.S. reduction and S.R.T. x temperature.

A definition of solids reduction under aerobic conditions must take into account both solubilization of particulates as well as carbon loss in a gaseous form. Changes in kinetic equilibrium between particulate biomass undergoing enzymatic solubilization, and soluble substrate being resynthesized back to particulate biomass may also account for differences in biomass reduction calculations.

As T.S.S. conversion increases, the rate of solubilization also increases. During October 1972, when performance was at a maximum, increase in the effluent T.D.S. accounted for approximately 30 percent of the T.S.S. converted. In March 1973, however, when performance was minimal, T.D.S. increase accounted for only five percent of the T.S.S. converted.

TABLE 1
Diffused Air System
Laboratory Data
S.R.T. (Days) Vs. Percent Change (Influent→Effluent)

S.R.T. (Days)	*Total Solids*	*Suspended Solids*		*Total Dissolved*	*C.O.D.*	*Nitrogen - N*			*Conductivity*	*pH*	*Alk.*
		TSS	*VSS*	*Solids*		*NO_3x10^3*	*NH_4*	*T.K.N.*	*μmho*	*Units*	*$CaCO_3$*
3.0 (a)	-11.0	-14.0	-15.8	+15.4	-19.0	+0.11	+20.5	-12.2	+13.4	0	+0.7
4.1 (b)	-15.9	-19.1	-22.3	+17.3	-27.0	+0.19	+61.7	-10.4	+19.0	+0.07	-8.5
6.3 (c)	-26.0	34.9	-40.5	+47.9	-42.0	+22.8	+97.1	-31.4	+31.9	-0.1	-27.8
8.6 (d)	-24.5	31.5	-40.6	+40.2	-42.2	+230	+44.7	-33.3	+44.3	0	-13.5
12.2 (e)	-32.5	-46.8	-50.9	+98.5	-50.8	+200	+141	-32.9	+73.5	-0.45	-63.4
18.3 (f)	-31.0	-43.2	-48.7	+97.9	-45.0	+445	+121.4	-44.8	+72.3	-0.40	-60.0
29.8 (g)	-28.7	-36.0	-39.3	+38.9	-41.2	+135	+77.3	-35.0	+46.0	-0.20	-36.5

Data Averaged From:
(a) January, February, August 1973
(b) December 1972, March, July 1973
(c) August, September 1972
(d) June 1973
(e) October, November 1972
(f) May 1973
(g) April 1973

Volatile Solids Reduction

Figure 3 indicates the volatile solids reduction achieved within the spectrum of temperature and loading conditions encountered during the full scale plant study. V.S.S. reductions ranged from 11.2 to 47.2 percent. Attempts to relate this performance to a single variable were unsuccessful. Beyond a certain limiting factor for sludge detention time, V.S.S. reduction was asymptotic, approaching but rarely exceeding 50 percent. When

The volatile fraction or V.S.S./T.S.S. ratio of the aerobically stabilized sludge must be reduced to 60 percent or less in order to avoid potentially obnoxious odors, particularly if the stabilized sludge is to be spread on land. This reduction has been impossible to achieve for sludge retention times of up to 30 days in this study. The volatile fraction of the aerobically stabilized sludge can be further reduced to the requiste 60 percent by either chemical oxidation (ozonation) or anaerobic digestion of the aerobic digester effluent.

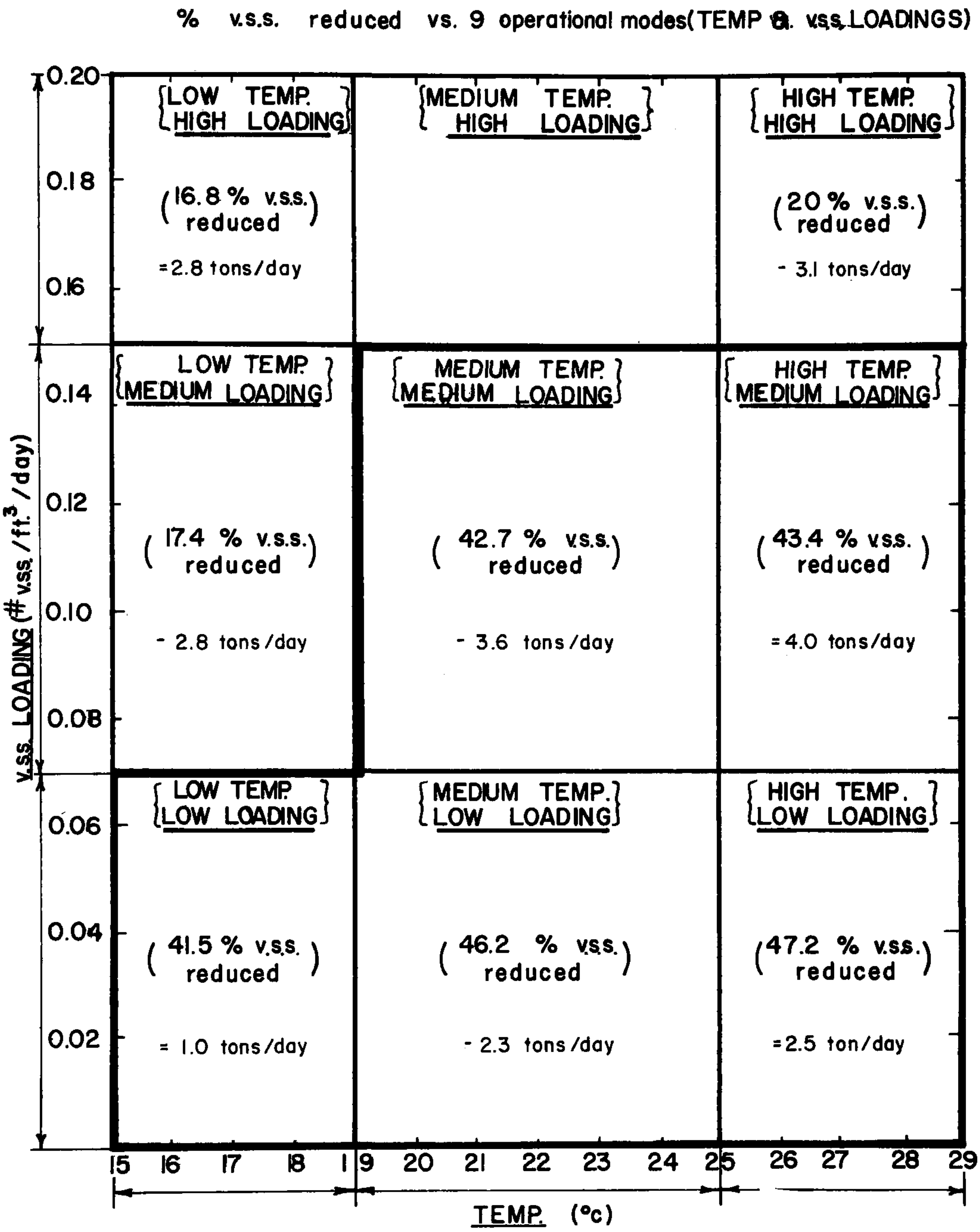

Figure 3: Metro Diffused Air System.

Influence of S.R.T. Before Aerodigestion on Volatile Solids Reduction

R. Loehr in his paper *Aerobic Digestion — Factors Affecting Design* has written, "Different rates of sludge oxidation and oxygen utilization are due to different starting points . . . (but) few authors report the sludge ages of solids entering the aerobic digester. The percent volatile solids reduction of a sludge with a high sludge age will be less than that of a sludge with a low sludge age. For waste sludges with a high sludge age, much of the sludge oxidation has taken place in the activated sludge (secondary) system."

The results obtained in the diffused air system at Metro Denver do not support Professor Loehr's contention that sludge age prior to aerobic digestion is a major influence on aerobic digestion performance.

For equivalent S.R.T. conditions (e.g. September — 12.8 days and December 1972 — 12.6 days) the degree of volatile solids reduction should be almost identical. However a 10°C drop in temperature between September (28.7°C) and December (18.4°C) resulted in a three fold drop in digestion rates from 47 percent V.S.S. reduced in September to only 16.6 percent in December. Solids reduction is apparently much more sensitive to environmental conditions during digestion (e.g. temperature) than to sludge prehistory.

Nitrogen Forms

Denitrification occurred when periods of maximum nitrification coincided with periods of insufficient oxygen (due to the shutting off of air in "C" pass for dewatering purposes). Because of the denitrification "split-float" the decanting operation was discontinued in September 1972.

The impact of sudden cold temperature onset on nitrification rates is illustrated in Table 2 which compares various parameters two weeks "before" and two weeks "after" the first winter snows (November 15, 1972 S.R.T. constant).

The cumulative decline in liquid temperature of ~1°C per day over a four day period (11/18 thru 11/21/72) resulted in a "cold shock" to the sensitive nitrifying bacteria. Adaptation of the nitrifying biomass to the colder temperatures is illustrated by the fact that nitrification was re-established in April 1973 even though temperatures reached the minimum monthly average of 15.9°C. During April the S.R.T. of 29.8 days was sufficient to maintain high nitrification rates despite the cold temperature. In July 1973 when biomass temperatures rose to 28°C and the S.R.T. dropped to 4.3 days nitrification inhibition was again observed.

No significant correlation was observed between temperature standardized oxygen uptake rate (k_{20}) and nitrification rates. The highest degree of nitrification occurred when k_{20} was at a minimum.

The most significant correlation (r = +0.96) between nitrification rates and environmental conditions was found for S.R.T. (days) x temperature (°C). Nitrate levels in excess of 100 mg/l N were observed when the temperatures weighted sludge retention time factor exceeded 200.

TABLE 2
Effect of "Thermal Cold Shock" on Nitrification Parameters

Parameter	*Units*	*Influent*	*Effluent* "Before"	*Effluent* "After"
Nitrate - N	mg/l	0.05	174	0.08
Ammonia N	mg/l	35	145	29
Alkalinity	mg/l	490	110	364
pH		7.0	6.0	7.0

Conductivity

The correlation between total dissolved solids and electrical conductivity is as expected very high. Thus, a simple method for estimating degree of stabilization achieved is measuring the change in electrical conductivity between the influent and effluent.

Microfaunal (Invertebrate) Analysis

Numerical counts were converted to a volumetric standard unit using previously determined dimensions for each particular organism observed. On a numerical basis, the smaller motile flagellates and ciliates comprised the great majority of organisms. When the numerical counts were converted to volumetric standard units, rotifers were found to comprise the great bulk of the invertebrate biomass.

Changes in invertebrate populations appear to be related to environmental stresses, particularly rate of temperature decline and organic loadings. August November 1972, when temperatures were above 22°C and volumetric loadings were less than 0.1 pounds V.S.S./ft^3/day, invertebrate diversity was at a maximum with the rotifer population assuming nearly half of the total dry weight biomass. During December 1972 when loadings increased to 0.187 pounds V.S.S./ft^3/day and temperature declined to 16°C, rotifers disappeared and ecological diversity declined.

The best performance (as expressed by volatile suspended solids reductions) was observed to occur during those months when invertebrate organisms comprised a significant fraction of the volatile suspended solids under aeration. The rotifer population appeared to have the most significant correlation with V.S.S. reduction. The coefficient of correlation between the rotifer population and the percent volatile suspended solids reduced was very high (r = +0.87).

Comparison of Aerobic and Anaerobic Stabilization

When activated sludge is anaerobically digested for 30 days, the V.S.S./T.S.S. ratio is usually reduced ~20 percent (e.g. from 80 to 60 percent). The amount of carbon lost from the anaerobic digester as methane and carbon dioxide is greater than the carbon dioxide lost from a continuous feed aerobic system where V.S.S./T.S.S. ratios decline by less than ten percent in 30 days. The concept "stabilization" must therefore be operationally defined in relation to odor potential for digested sludges disposed of on land.

When the "partially stabilized" aerobic digester effluent having a volatile solids residue of about 76 percent is loaded to an anaerobic digester (S.R.T. = 18 days) the V.S.S./T.S.S. ratio is further reduced to 62 percent. This "double digested" material can be spread on land without fear of subsequent odor problems.

Odor Panel Results

The most important indicator of sludge stability from an aesthetic viewpoint is odor. In order to define this problem quantitatively, a seven person panel was formed to periodically monitor the odor potential of three 50 gallon samples spread over 10 square foot plots.

Odor results for three sludge mixtures (anaerobically digested primary sludge, aerobically digested sludge and a mixture (1:1 ratio) of both sludges) were evaluated during a 28 day period. The aerobically digested sludge (volatile solids fraction = 75 percent) had the least offensive odor. When this sludge was mixed in a 1:1 ratio with anaerobically digested sludge (volatile fraction = 60 percent) a definitely objectionable odor occurred. The so called "nonbiodegradable" fraction of the aerobically digested volatile suspended solids can be further biodegraded by an adapted anaerobic bacterial culture. Thus offensive odors are a definite possibility if aerobic sludge residues having V.S.S./T.S.S. ratios greater than 60 percent are allowed to go septic.

Supernatant Quality

Aerobically digested supernatants are much less concentrated than anaerobic digestion supernatants. The C.O.D., T.K.N. and NH_4 concentrations in the aerobic digester supernatant averaged only 13 percent of the concentrations in supernatant from an anaerobic digester pilot plant digesting W.A.S. The aerobic supernatant B.O.D. and T.S.S. concentrations were only ten percent (100 mg/1) of the average anaerobic concentrations.

Dewaterability

Vacuum filter leaf tests indicated that for an equivalent chemical cost, better vacuum filter performance is obtained with the aerobically digested sludge, as compared with fresh waste activated sludge.

The sand filtration rates of the aerobically digested and undigested sludges are approximately equal. Aerobically digested sludge drained three times as fast as anaerobically digested sludge on a volumetric basis. On a solids weighted basis, however, the anaerobically digested sludge drained 2.5 times faster than the aerobically digested sludge, and the fresh W.A.S. drained 20 percent faster than the digested sludge.

Sludge concentration by dissolved air flotation is affected by the particle surface area available for cationic polymer conditioning. An inverse relationship between polymer demand and sludge loading rates was observed. If an optimal loading (0.10 pounds V.S.S./ft^3/day) to the digester is maintained, significant savings in polymer costs for sludge thickening can be realized. If very long S.R.T.'s are maintained, the polymer costs may rise to double that required for the undigested waste activated sludge.

Pure Oxygen Pilot Plant — Batch Tests

The five batch tests using pure oxygen indicated that the rate of biodegradable volatile solids reduction levels off after approximately 15 days. Readily biodegradable V.S.S. was arbitrarily defined as that fraction of the total V.S.S. reduced by the end of each test run. Because of alternate periods of auto digestion and re-synthesis, the final sample did not always have the lowest V.S.S. concentration.

Table 3 summarizes the biomass reduction data for all five batch tests. Of the five tests run, Batch Test No. 3 was unique in that a previously diffused air digested material was used as the starting sludge. Test runs, 1, 2, 4 and 5 were loaded with fresh waste activated sludge.

The V.S.S./T.S.S. ratio was significantly higher for the fresh sludge (84.5 percent) as compared with the air digested waste activated sludge (79.9 percent). The final sample V.S.S./T.S.S. ratio for test runs 1, 2, 4 and 5 averaged 79.6 percent while the V.S.S./T.S.S. ratio for run 3 actually increased slightly to 82.6 percent. All runs experienced alternative periods of accelerated endogenous decay followed by periods of re-synthesis. The average of the four runs using fresh W.A.S. showed a net reduction of five percent in the V.S.S./T.S.S. ratio.

The volatile suspended solids reduced (based on the difference between the initial and final sample) averaged 45.7 percent for test runs 1, 2, 4 and 5,

TABLE 3
Pure O2 - Batch Tests
Mass Reduction Data Summary

Sample	Test No.	Detention Time Days	VSS/TSS Ratio Initial	VSS/TSS Ratio Final	VSS/TSS Ratio Δ %	% V.S.S. Reduced*	Biodegradable Aerobic Digestion Rate Coefficient k_{vss}	Biodegradable Aerobic Digestion Rate Coefficient k_{cod}
W.A.S. Undigested	1	21	0.865	0.844	-2.1	53.7	0.143	
W.A.S. Undigested	2	15	0.826	0.750	-7.6	54.7	0.175	
W.A.S. Undigested	4	21	0.859	0.844	-1.5	30.5	0.204	0.174
W.A.S. Undigested	5	14	0.829	0.744	-8.5	43.7	0.273	0.190
Average			0.845	0.796	-5.0	45.7	0.200	0.182
W.A.S. Air Digested	3	21	0.799	0.826	+2.7	35.3	0.182	

*Based on initial versus final V.S.S. concentration.

compared with 35.3 percent for test run 3. The most efficient utilization of pure oxygen is obtained by using a non-digested waste activated sludge with a high initial V.S.S./T.S.S. ratio.

The only study published to date on aerobic digestion where pure oxygen was used on a large scale is EPA Report No. 17050DNW02/72. The aerobic digestion experiments in this study at Batavia, New York were performed entirely on an already oxygenated waste activated sludge having low V.S.S./T.S.S. ratios (67.6 to 74.1 percent). Figure 4 compares results for runs 6 and 8 at Batavia with Batch Test No. 5 of this study. The aerobic digestion rate coefficient for readily biodegradable V.S.S. in the Batavia study was k = 0.12 compared to k = 0.27 in this study. Figure 4 shows that 20 percent of the readily biodegradable V.S.S. remains in the Metro batch system at sludge retention time of six days, compared with 48 percent biodegradables remaining in the Batavia system.

The instantaneous oxygen uptake rate was found to be proportional to readily biodegradable volatile suspended solids above a concentration of 2,000 mg/1. Endogenous respiration must be proportional to the active mass rather than the total volatile suspended solids. Below 2,000 mg/1, changing metabolic states make this level of activity non-linear. In the Metro study, the equation for oxygen uptake rate for solids concentrated above 2,000 mg/l was found to be:

$$\text{O.U.R.} = 0.0127 \text{ V.S.S.} \\ \text{(Biodegradable)} + 39.7$$

(with a correlation coefficient r = +0.90).

The poor linear relationship that was found to exist in the Batavia study between O.U.R. and V.S.S. became a very significant relationship if the readily biodegradable V.S.S. above 2,000 mg/1 is substituted for total V.S.S.

The results of the pure oxygen batch test portion of this study yield the following conclusions:

1. A stabilized sludge (40 50 percent volatile suspended solids reduction) was obtained after one to three weeks of detention time. These values are significantly higher than the 20 to 30 percent reduction values reported in the Batavia report.
2. No correlation was observed during any of the tests between dissolved oxygen concentration and V.S.S. digestion rates. The highest dissolved oxygen rates occurred when the oxygen uptake rate and the V.S.S. digestion rate were at a minimum. It appears that above the minimal concentration required to sustain aerobic metabolism (1.0 mg/1) D.O. concentrations are a result rather than a cause of aerobic digestion reaction rates.
3. A high degree of oxygen utilization (~92 percent) was demonstrated in the pure oxygen open tank system (Batch Test No. 5).
4. Erratic variations in V.S.S./T.S.S. ratios during the various batch tests may be explained by the cyclical periodicity of alternate auto digestion followed by re-synthesis of biomass using previously solubilized nutrients (cryptic growth).
5. High concentrations of suspended solids results in a stressful "crowding" situation that is

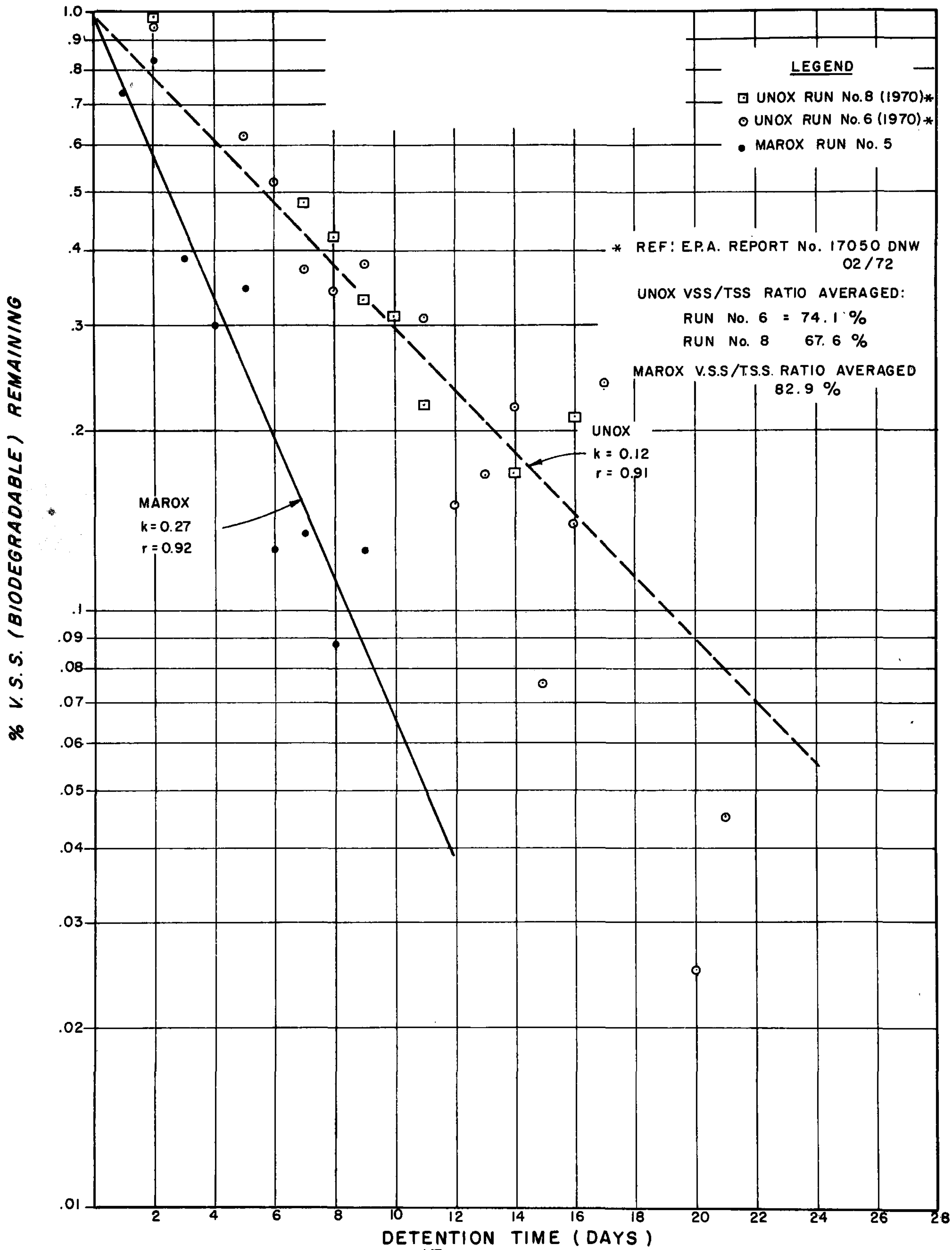

Figure 4: Pure O_2 Batch Test Comparison of UNOX and MAROX Data—Reduction of Readily Biodegradable V.S.S. vs. Detention time.

in-imitable to successful growth and reproduction of invertebrate organisms in the batch test digester. The addition of cationic high molecular weight polymers to the sludge during dissolved air flotation may also adversely affect the ecological diversity of this system. At the end of Batch Test No. 1, only one of the common invertebrate group (micro flagellates) could be observed in a viable condition, while no moving invertebrate organisms could be observed at the end of Batch Test No. 2. In the pure oxygen batch tests, mass decay and endogenous respiration are accomplished almost entirely by bacteria rather than higher invertebrate organisms.

6. The relative differences in performance between the aerobic digestion oxygen studies at Batavia and this study may be a result of differences in mixing energy, initial volatile solids concentration, different methods of transferring oxygen from the gaseous to the liquid phase and carbon dioxide/pH differences between the initial and final samples. A master's thesis by Thomas J. Weston of Michigan Technological University concluded that the oxygen unit achieved lower solids reduction and exhibited lower oxygen uptake rates than the air unit. The author mentioned that in his closed tank system oxygen digested sludges had significantly lower pH value (4.9) and concluded that pH toxicity may have affected the biological activity of the system. The average volatile solids reduction in Weston's pure oxygen digester was only 23.7 percent compared with 41.3 percent in the air digester for an equivalent detention time.

The unique nature of the Marox fine bubble diffuser allows for purging of carbon dioxide and volatile organic acids from the open tank system. Thus the final pH is more alkaline than in the Batavia study. The continuous recycling of the liquid sludge through the gas/liquid diffuser to create minute gas bubbles aides in purging CO_2 from the system, and also involves a high degree of mixing energy which can be related to the high rate of volatile solids reduction achieved.

Pure Oxygen Continuous Feed Pilot Plant — Slot Diffuser

The major objective of this part of the test program was to determine the breakdown loading rate to the system. The first three phases were designed to duplicate the loading range that had been applied to the diffused air system (0.083 to 0.196 pounds V.S.S./ft^{3}day). The last two phases of this test investigated the performance at much higher loading rates (0.326 to 0.433 pounds V.S.S./ft.^{3}/day).

At the lowest loading rate (0.083 pounds V.S.S./ft^3/day) there was virtually no difference between air and biomass temperatures. At the highest loading rates (0.433) the temperature differential increased to 20°C (i.e., ambient temperature averaged 8.4°C while the biomass in Tank B averaged 28.6°C).

Table 4 summarizes the aerobic digestion performance for the five phases of the flow through pilot plant using the slot diffuser. Aerobic digestion performance (measured as percent V.S.S. reduced) declined only slightly from 47.1 percent at the lowest loading rate to 38.8 percent at the highest loading rate, and averaging 42.7 percent for the entire period. The maximum loading rate beyond which performance breaks down was therefore not determined.

Pure Oxygen Continuous Feed Pilot Plant — Rotating Diffuser

The major objectives of these tests were to demonstrate the capability of the rotary diffuser to aerobically digest thickened W.A.S. without prescreening with a high degree of O_2 transfer efficiency ($>$ 80 percent), and a high rate of V.S.S. reduction ($>$ 30 percent).

The first objective was demonstrated satisfactorily during a sixty day test period. No indication of diffuser plugging appeared, despite the removal of prescreening. All of the other objectives were also realized and the overall performance exceeded expectation. Table 5 summarizes the aerobic digestion performance for the two test runs using the rotating diffuser.

Test Run No. 1 was loaded at 0.60 pounds V.S.S./ft^3/day while the loading for Test Run No. 2 was reduced to 0.43 pounds V.S.S./ft^3/day.

The pounds of oxygen supplied per pounds V.S.S. reduced, averaged 1.54 for the two runs with the second test averaging 1.36. This performance can be compared with phase 5 of the flow through slot diffuser test which required 2.68 pounds O_2 supplied per pound V.S.S. reduced. Thus, the results of the second rotating diffuser test represents a reduction of 50 percent as compared with the slot diffuser test at identical loadings. The S.R.T. and hydraulic detention time averaged 5.3 days and 4.1 days respectively, indicating the feasibility of high volumetric loadings and low space requirements for large scale operations.

TABLE 4
Pure O_2 - MAROX Flow Through Pilot Plant Solids Data Summary (V.S.S.)

Phase		Loading # VSS/Ft³/Day	Feed #/Day	Waste #/Day	Inventory ΔLbs/Day	Inventory (Lbs.)	Retention Time (Days) S.R.T.	Retention Time (Days) Hydraulic	# O_2/# VSS Digested Respired	# O_2/# VSS Digested Supplied	Aerob. Digest. #/Day	Aerob. Digest. %
I	Mean	0.083	38.0	19.0	+1.1	855	63.3	22.3	N.A.	6.93	17.9	47.1
	Min.	0	0	0				18.8				
	Max.	0.135	81.9	171.5				28.2				
II	Mean	0.139	64.3	35.8	+1.1	884	25.3	15.7	N.A.	3.76	27.4	42.6
	Min.	0	0	0				11.0		--		
	Max.	0.188	92.4	76.8				23.3	-			
III	Mean	0.196	90.3	52.9	-3.8	806	16.6	10.7	1.94	2.96	41.2	45.6
	Min.	0.092	42.3	31.2				6.4				
	Max.	0.293	134.9	98.0				21.9				
IV	Mean	0.326	150.1	88.3*	+2.4	866	10.2	6.7	1.70	2.37	59.4	39.6
	Min.	0.230	127.0	59.4				5.8				
	Max.	0.421	193.8	138.4				12.8				
V	Mean	0.433	199.2	120.9	+1.0	921	7.9	5.4	1.49	2.68	77.3	38.8
	Min.	0.301	152.3	90.9				5.0	-			
	Max.	0.579	266.2	186.2				6.4				
Total 159 Days	Mean	0.235	108.4	63.4	+0.36	866	13.7	9.1	1.70	3.10	44.6	42.7

Phase I - 6/11 - 7/13/73
Phase II 7/14 - 8/22/73
Phase III 10/20 - 11/19/73
Phase IV 11/20 - 12/13/73
Phase V 12/14 - 1/13/74

*including spills

TABLE 5
Pure O_2 MAROX Flow Thourgh Pilot Plant - Rotating Diffuser Solids Data Summary (V.S.S.)

Test Run	Loading Lbs V.S.S./Ft³/Day	Feed Lbs/Day	Waste Lbs/Day	Inventory Lbs/Day	Inventory Lbs	Retention Time (Days) S.R.T.	Retention Time (Days) Hydraulic	Aerob. Dig. Lbs/Day	Aerob. Dig. %
1. Mean	0.60	137	92	-3.0	424	4.7	3.7	48.4	35.3
Min.	0.47	108	64			3.1	2.3		
Max.	0.93	213	130			6.2	4.7		
2. Mean	0.43	99	66	+0.7	386	5.8	4.5	31.5	32.0
Min.	0.34	79	59			5.2	4.1		
Max.	0.51	118	82			6.6	5.4		
Total Mean 57 Days	0.515	118	79	-1.6	405	5.3	4.1	40.0	33.7

Test Run No. 1 - 3/10 - 4/10/74
Test Run No. 2 - 4/11 - 5/5/74

The data obtained with the rotary diffuser represents a significant breakthrough in the technology of pure oxygen aerobic digestion, by obtaining a high degree of mass reduction at economic oxygen utilization levels in thickened waste activated sludge (~ 5 percent T.S.) without screening problems. This technology represents an attractive alternative to other processes for W.A.S. handling and disposal.

Comparison of Diffused Air and Oxygen Performance

A major difference between the air and oxygen systems relates to the temperature ranges experienced with each system. Whereas air system temperatures were subject to sudden changes, the pure oxygen pilot plant system was conducted indoors, and was therefore not subject to cold temperature shock. Significant increases in biomass temperature occurred with the oxygen systems particularly during the initial batch tests.

The sudden decline in oxygen uptake rates with increase of temperatures above 40°C indicates that the mesophilic biomass may have been replaced by thermophilic bacterial culture. The intermediate temperature range of 40 to 50°C is an inefficient range for accomplishing rapid volatile suspended solids reduction. During the flow through pure oxygen pilot plant testing using the slot diffuser, the biomass temperatures increased in direct relation to the loading rates, with the maximum increase of 20°C being experienced at the highest loading rate (0.043 pounds V.S.S./ft^3/day). The ability to maintain high loading rates in thickened waste activated sludge suggests the possibility of thermophilic aerobic digestion with accelerated rates of V.S.S. reduction, if the oxygen system were to be enclosed and insulated to conserve the heat generated. It would, however, be necessary to ensure that the thermophilic cultures were consistently maintained above the minimum temperatures required for optimal growth and development, in order to avoid cycling between mesophilic and thermophilic conditions with subsequent unpredictability of biological performance.

A further difference between the air and oxygen systems relates to the influence of sludge retention time prior to aerobic digestion on the ultimate rate of V.S.S. reduction. While the sludge retention time of the activated sludge system prior to loading the aerobic digester appeared to have little influence on the rate of volatile suspended solids reduced, the opposite was the case during the batch tests with pure oxygen.

It appears that the major factor determining digestion rates is not S.R.T. per se, but rather the initial V.S.S./T.S.S. ratio. Very small differences in this ratio were observed in the activated sludge loaded to the diffused air aerobic digester. A significant reduction in the V.S.S./T.S.S. ratio was noted however in the air digested sludge loaded to the pure oxygen pilot plant.

Endogenous respiration ensures that the effluent from an aerobic digester will have a lower volatile solids ratio than the initial sample. There does not appear to be any advantage in two stages of aerobic digestion, that is diffused air digestion followed by pure oxygen digestion. If a pure oxygen system is available, the best use of plant resources would indicate that activated sludge be loaded directly to the oxygen system, without an intermediary diffused air step.

A quantative measure of sludge stability is the specific oxygen uptake rates (kr). Whereas, in the oxygen batch tests kr of less than 1.0 was achieved in ten days, the flow through air and oxygen systems k_r ranged from four to six. The high oxygen uptake rates are attributable to metabolic resynthesis oxygen requirements using lysed metabolites. No significant correlation between k_r and nitrification rates was observed with either the air or the oxygen system. Similarly, no relation was observed between the dissolved oxygen concentration and the rate of aerobic digestion up to 16.6 mg/1. Contrary to some statements in the literature regarding the influence of dissolved oxygen concentrations on digestion levels, it appears that dissolved oxygen concentration is an effect rather than a cause of changing oxygen uptake rates. When oxygen uptake rates decline, dissolved oxygen concentrations tend to increase, if the oxygen supply is constant.

The solids specific oxygen uptake rate (k_r) averaged 7.1 for the air system compared with 5.0 in "A" tank and 4.3 in "B" tank of the pure oxygen system. On the basis of the differential between initial and final V.S.S./T.S.S. ratios achieved in both the air and the oxygen systems, an empirical standard for a stabilized sludge of $k_r < 5$ appears reasonable.

The percent reduction in solids forms achieved for both the air and oxygen systems versus loading rates and detention time is depicted in Figure 5. At loadings greater than 0.15 pounds V.S.S./ft^3/day, the percent V.S.S. reduction is greater with the oxygen system than the air system.

Conversely, at loading rates below 0.10 pounds V.S.S./ft^3/day the reduction of all solids forms is greater with the air system than the oxygen system.

The degree of solubilization achieved is greater at all loading rates for the oxygen system than for the air system. The oxygen system is better able than the air system to maintain a high degree of volatile suspended solids reductions at very high loading rates that cannot be maintained in the air system because of oxygen transfer capability limitations.

Conversion rates of total kjeldahl nitrogen to nitrates, ammonia and nitrogen gas were significantly different in the oxygen and air systems. For the air system (during those periods when temperature conditions were favorable for nitrification) most of the T.K.N. conversion was exhibited as an increase in NO_3. Approximately half of the T.K.N. was converted to nitrate, while one-quarter of the kjeldahl nitrogen conversion was expressed as an increase in ammonia concentration. The remainder of the T.K.N. conversion was due to denitrification during periods of low dissolved oxygen

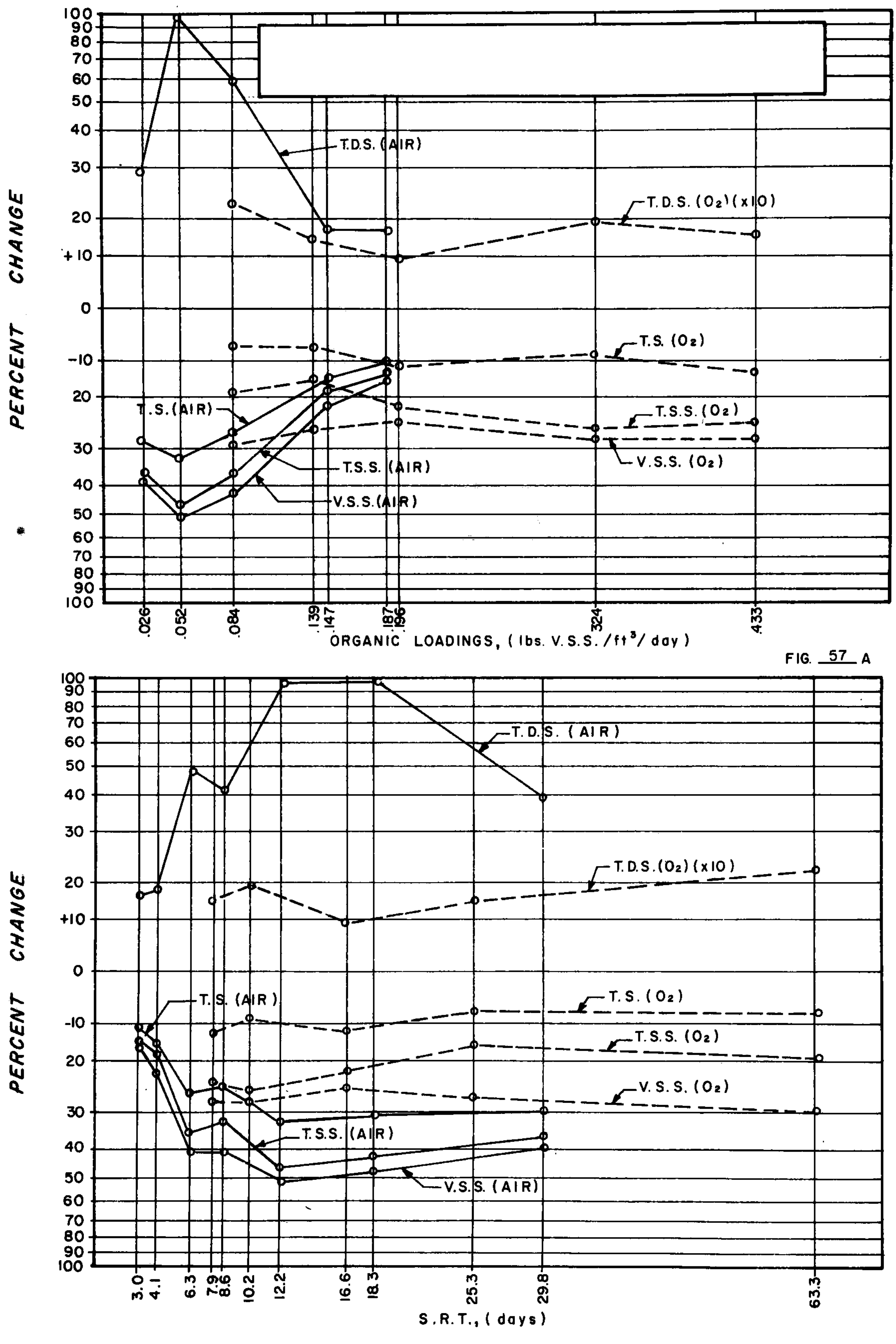

Figure 5: Air vs. Oxygen Aerobic Digestion—Solids Percent Change.

concentration. Whereas a very good correlation was observed between nitrification and S.R.T. x temperature for the diffused air system, no such correlation was observed for the oxygen system. High nitrification rates were observed in several of the oxygen batch tests, but minimal nitrification occurred in the flow through tests. It is assumed that the conditions of crowding at high loading rates as well as polymer conditioning and high mixing energy do not provide a suitable environment for rapid growth and reproduction of nitrifying bacteria.

Nitrate concentrations in the air system increased by a factor of 10^5 between influent and effluent at a S.R.T. of 8.6 days. The highest nitrate levels observed in any of the oxygen phases was less than 5 mg/1 NO_3-N.

Ammonium ion concentrations were significantly higher in the oxygen system than the air system at all loading rates. At organic loadings of 0.187 pounds V.S.S./ft^3/day, ammonia increased in the air supply by only twelve percent versus 150 percent in the oxygen system. It is apparent that the oxygen system converts more kjeldahl nitrogen to ammonia, whereas the air system (at equivalent loadings) oxygenates more of the ammonia to nitrates.

Figure 6 compares V.S.S. reduction rates with loading rates for both the oxygen and air systems. At loading rates below 0.08 pounds V.S.S./ft^3/day the air system results are equal or better than the oxygen system. Up to loading rates of 0.14 pounds V.S.S./ft^3/day the performance of the oxygen air systems was roughly equal. Above 0.14 pounds V.S.S./ft^3/day the performance of the air system declines rapidly, whereas the oxygen system continues to perform well up to loading rates as high as 0.6 pounds V.S.S./ft^3/day.

Figure 7 shows the oxygen utilization efficiency (expressed as pounds O_2 supplied per pound V.S.S. reduced) versus loading rates. Three different ranges of oxygen efficiency related to three different oxygen transfer methods are illustrated. The best diffused air performance requires 15 pounds of O_2 supplied per pound V.S.S. reduced. The best performance for the pure oxygen slot diffuser system requires 2.3, and the best pure oxygen rotating diffuser system performance requires 1.36. Whereas with the diffused air system, the optimal loading rate for high oxygen transfer efficiency was 0.08, the optimal loading range for the pure oxygen system was the highest loading possible. With the diffused air system, the change in oxygen transfer efficiency varied with temperature and liquid depth, ranging between 5.2 to 19.3 percent. The major factor influencing oxygen transfer efficiency with the oxygen system was the degree of plugging experienced. With the slot diffuser oxygen efficiencies as high as 93 percent were experienced in one of the batch tests. This level could not be consistently maintained for several months at a time during flow through testing. With the substitution of the rotating diffuser for the slot diffuser, oxygen transfer efficiencies in excess of 90 percent were consistently achieved for several months of continuous operation. In order to ensure high percent transfer efficiencies with an open tank pure oxygen system, it is necessary that dissolved oxygen never exceeds the saturation concentration at the air/liquid interface.

Comparison of dewaterability of aerobically digested sludges from the diffused air and oxygen systems indicate no significant differences in specific resistance ($r \doteqdot 10^9$ sec^2/gr) between influent and effluent samples for sludge retention times between three and thirteen days. Differences in filter leaf performance tests were however observed.

For a dilute sludge without polymer conditioning, aerobic digestion improves vacuum filter performance by reducing the volatile fraction. After digestion of polymer thickened sludge, however, there is an adverse effect on vacuum filter performance related to the decrease in solids concentration. The effect of detention time on flotation polymer demand for the diffused air system is directly related to particle size and T.S.S./V.S.S. ratio. The higher the S.R.T. of the sludge in the air system, the higher the ultimate polymer demand.

The invertebrate population as a part of the total volatile suspended solids biomass was reduced by 80 percent between the diffused air aerobic digester effluent and "A" tank of the oxygen system, and was further reduced by 77 percent between "A" and "B" tank. Temperature changes and loading stresses influenced population dynamics in the diffused air system, while it is assumed that the conditions of crowding and the high rate recycling mixing energy in the pure oxygen system created an environment which was inimicable to growth and reproduction of higher invertebrate forms.

FUTURE PLANS

Since the initial conversion of 8 M.G. secondary aeration capacity to aerobic digesters in 1970, increased loadings to the secondary process have necessitated a cutback in the aerobic digestion facility to 4 M.G. By 1975, all of the presently operat-

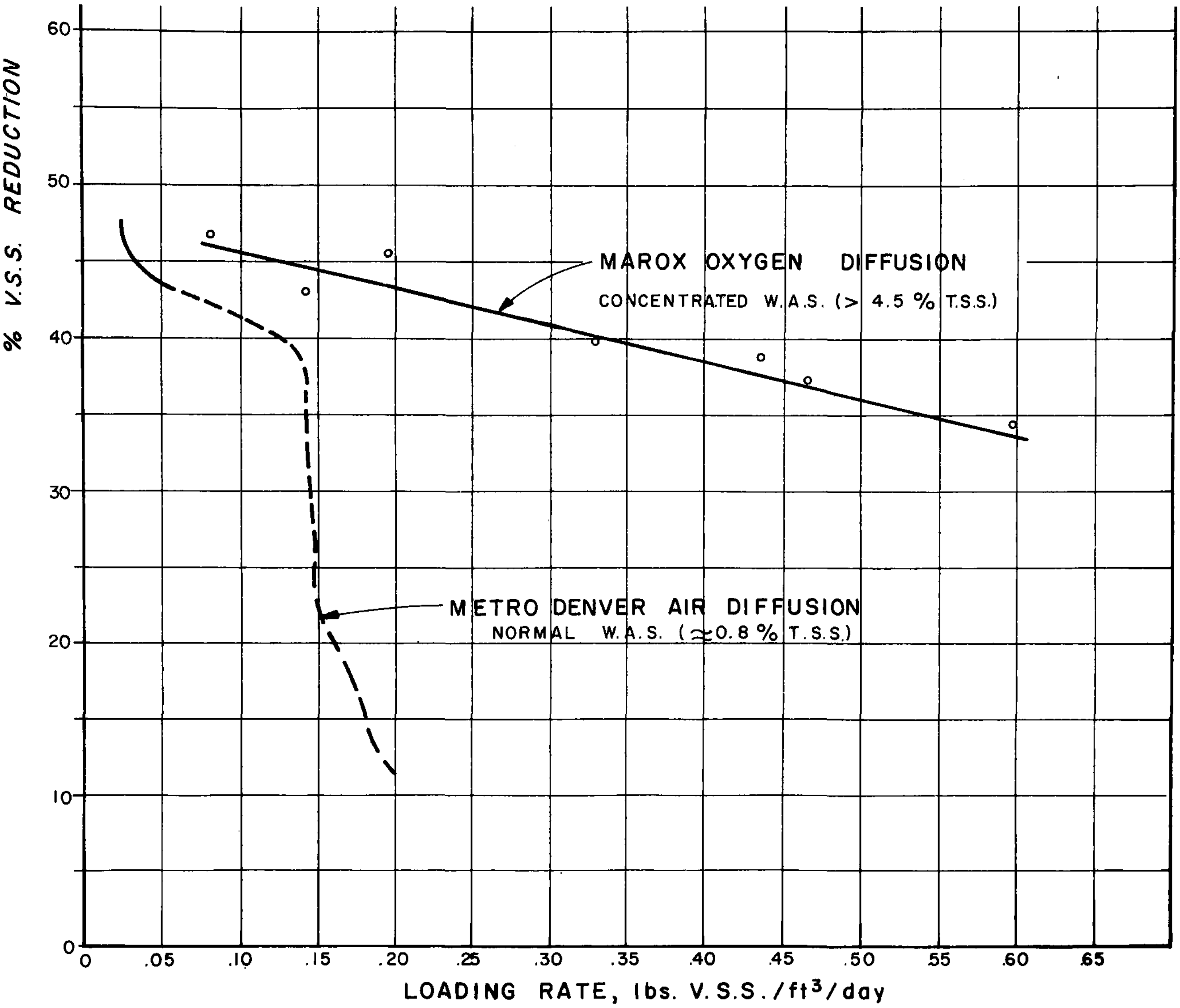

Figure 6: V.S.S. Reduction vs. Loading Rates.

ing aerobic digesters will have to be converted back to secondary aeration basins. In order to continue to obtain the benefits of reduced sludge disposal costs resulting from aerobic digestion, Metro Denver is at present considering the conversion of a 1 M.G. sludge holding tank to a pure oxygen aerobic digestion system using the rotating diffuser. The oxygen digested sludge would be further digested anaerobically for about two weeks to ensure a final product having less than 60 percent volatile fraction suitable for land application.

ACKNOWLEDGEMENT

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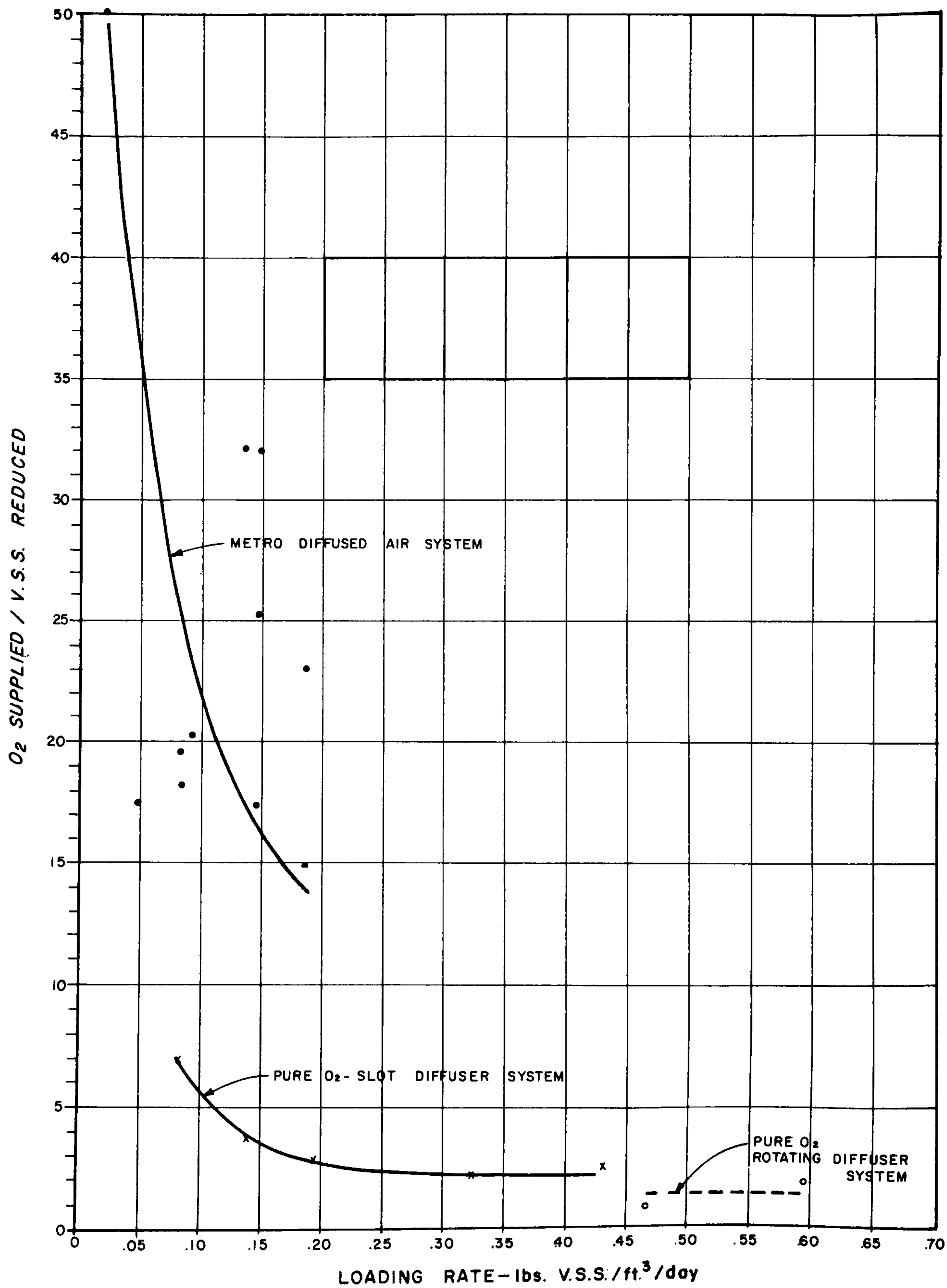

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HIGH PURITY OXYGEN AEROBIC DIGESTION EXPERIENCES AT SPEEDWAY, INDIANA

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ABSTRACT

A full scale aerobic digestion study utilizing high purity oxygen was performed at the Speedway, Indiana Water Pollution Control Plant. The major purpose of this study was to investigate the possibility of attaining and operating at elevated temperatures without an external heat source. The existing UNOX System* was modified so that the entire wastewater flow from the primary clarifier could be handled by one of the two available reactor trains while the other train served as an aerobic digestion unit. The oxygen aerobic digestion process showed the capability of sustaining high temperatures (>31°C) during winter operation through the conservation of energy produced by endogenous decay. Volatile suspended solids reductions in excess of 43 percent were obtained with retention times as short as 11.6 days.

Utilizing the data obtained from these tests a full scale aerobic digestion system using high purity oxygen was designed for Speedway, Indiana. The economic evaluation of the design indicates that the annual cost for aerobically digesting Speedway waste sludge is $53,400 which represents a cost of $34.00 per ton of dry solids treated.

INTRODUCTION

Aerobic digestion is a process designed to stabilize waste primary and/or waste activated sludge through the catabolism of aerobic microorganisms. Catabolism, in the form of endogenous metabolism, is the self destructive activity that results in the breakdown of complex materials within the microorganism. This cellular destruction involves the release of energy and a reduction in the population of viable organisms within the system. Generally, the rate at which the biodegradable volatile suspended solids (BVSS) concentration decreases within a digester is used as a measure of the rate of this endogenous metabolism occurring within that system.

If the cell mass of a microorganism can be approximated by the formula $C_5H_7NO_2$ then the catabolic activity in an aerobic digestion system can be represented by either one of the following two equations:

$$C_5H_7NO_2 + 5O_2 \rightarrow 5\,CO_2 + 2H_2O + NH_3 \quad (1)$$
$$C_5H_7NO_2 + 7O_2 \rightarrow 5\,CO_2 + 3H_2O + NO_3^- + H^+ \quad (2)$$

Equation (1) represents a process operated at conditions that inhibit the growth of organisms known to cause nitrification. From this expression it is possible to calculate a theoretical oxygen requirement (1.4 lbs. O_2/lb. $BVSS_{reduced}$ as well as a theoretical respiration coefficient (1.0 moles CO_2 produced/mole O_2 used). In designing an aerobic digestion unit utilizing either pure oxygen or air it is imperative that the oxygen requirements and respiration coefficient be known so that the oxygen supply and mass transfer equipment can be properly sized. In a closed system the CO_2 concentration in the gas has an adverse effect on the driving force for O_2 dissolution.

Equation (2) is indicative of a system where the conditions are acceptable for the propagation of nitrifying organisms. In this case the theoretical oxygen demand and respiration coefficient for the

*UNOX is a registered trade mark of UNION CARBIDE CORPORATION. The UNOX System is covered by patents in the U.S.A. and foreign countries.

process are 1.98 lbs. O_2/lb. BVSS reduced and 0.71 moles CO_2 produced/mole O_2 used, respectively.

As was presented earlier, the catabolic activity of microorganisms involves the release of energy. Andrews and Kambhu[1] indicated that the energy released by the exothermic reactions represented in equations (1) and (2) can approach the heat of combustion of waste sludge, 9,000 BTU/lb. VSS destroyed. However, some energy is required for cell maintenance. According to McCarty[2], energy is required for mobility, the prevention of undesirable flow of solutes across membranes, and the resynthesis of proteins that are constantly degraded due to kinetic instability. Therefore the difference between the heat of combustion and the maintenance energy is the free energy liberated through the digestion process.

The kinetics of aerobic digestion are generally accepted to be a first order rate phenomenon. The rate of BVSS oxidation is first order with respect to the BVSS concentration (Equation 3).

$$\frac{d(BVSS)}{dt} = -K_D\,(BVSS) \qquad (3)$$

Further, the variation in the endogenous decay (K_D) coefficient is believed to follow an Arrhenius relationship (Equation 4). Therefore, as the temperature of the system increases the rate of stabilization increases.

$$K_D \quad K_{D20}\,\Theta^{(T-20)} \qquad (4)$$

Because of the exothermic nature of digestion reactions and the increase in rate of digestion with temperature it was anticipated that the totally enclosed pure oxygen system would provide a number of significant advantages over an open air system for aerobic digestion. Because of the high utilization of oxygen expected for the process, less heat should be lost in the form of (1) sensible heat of the vent gas and (2) heat of vaporization of water within the vent gas and thus a higher temperature should be attained. Also the reduction in heat loss due to the covered oxygen system tankage should permit better retention of the energy liberated by digestion and, consequently, higher operating temperatures.

Literature data[3,4,5] indicate that the performance of aerobic digesters is very sensitive to the D.O. level. Consequently, the EPA recommends[8] a minimum D.O. concentration of 2 mg/1 be maintained to insure proper performance. As already indicated, at the higher temperatures the rate of endogenous decay increases but, unfortunately, the driving force for O_2 dissolution decreases. This decreased driving force at elevated operating temperatures manifests itself as an increase in the power necessary to dissolve the oxygen required for the aerobic digestion process. In air digesters the inordinately high dissolution power required to maintain a D.O. concentration of 2 mg/1 when operating at elevated temperatures is oftentimes an uneconomic operating mode. Because of the high gas phase oxygen purities (and the concomitant increased driving force), it was anticipated that an oxygen aerobic digester could economically operate at elevated temperatures and high D.O. concentration. Therefore, the Speedway, Indiana study was initiated to demonstrate the inherent operating advantages of using high purity oxygen for aerobic digestion.

Procedure

The Speedway, Indiana Wastewater Treatment Plant Facility consists of primary sedimentation units, a UNOX System, a Zimpro LPO System for treating the combined waste sludges (oxygen activated sludge and primary), and a vacuum filter for dewatering the heat treated sludge before land disposal.

The plant was designed for 7.5 mgd with a maximum storm capacity of 18 mgd. The actual flow to the system during the operation of the digestion process in late 1972 was about 4 mgd.

The UNOX System at Speedway is presented in Figure 1. The plant consists of two biological reactor trains with each train containing a series of four concurrent gas-liquid stages. During the aerobic digestion study the two trains were operated as completely independent systems. The south side of the reactor train was chosen to handle the 4 mgd of wastewater because it is better instrumented and has access to two clarifiers. The aerobic digestion reactor, north side, required only one clarifier which was used as a holding tank for the aerobically digested sludge.

Each stage of the aerobic digestion reactor had the dimensions 22 ft.×22 ft. and operated with a 16 ft. liquid depth. The total volume of the digester was 232,000 gallons. The clarifier was 65 ft. in diameter with a 10 ft. liquid depth.

Aeration and mixing in the digestion unit was performed by the existing equipment. Each stage contained a 45° P.B.T. surface aerator. with a supplementary bottom mixer. The horsepower ratings for the mixers were 10, 7.5, 7.5 and 7.5 for stages one through four, respectively.

The aerobic digester was operated on a semi-continuous basis. The waste UNOX System

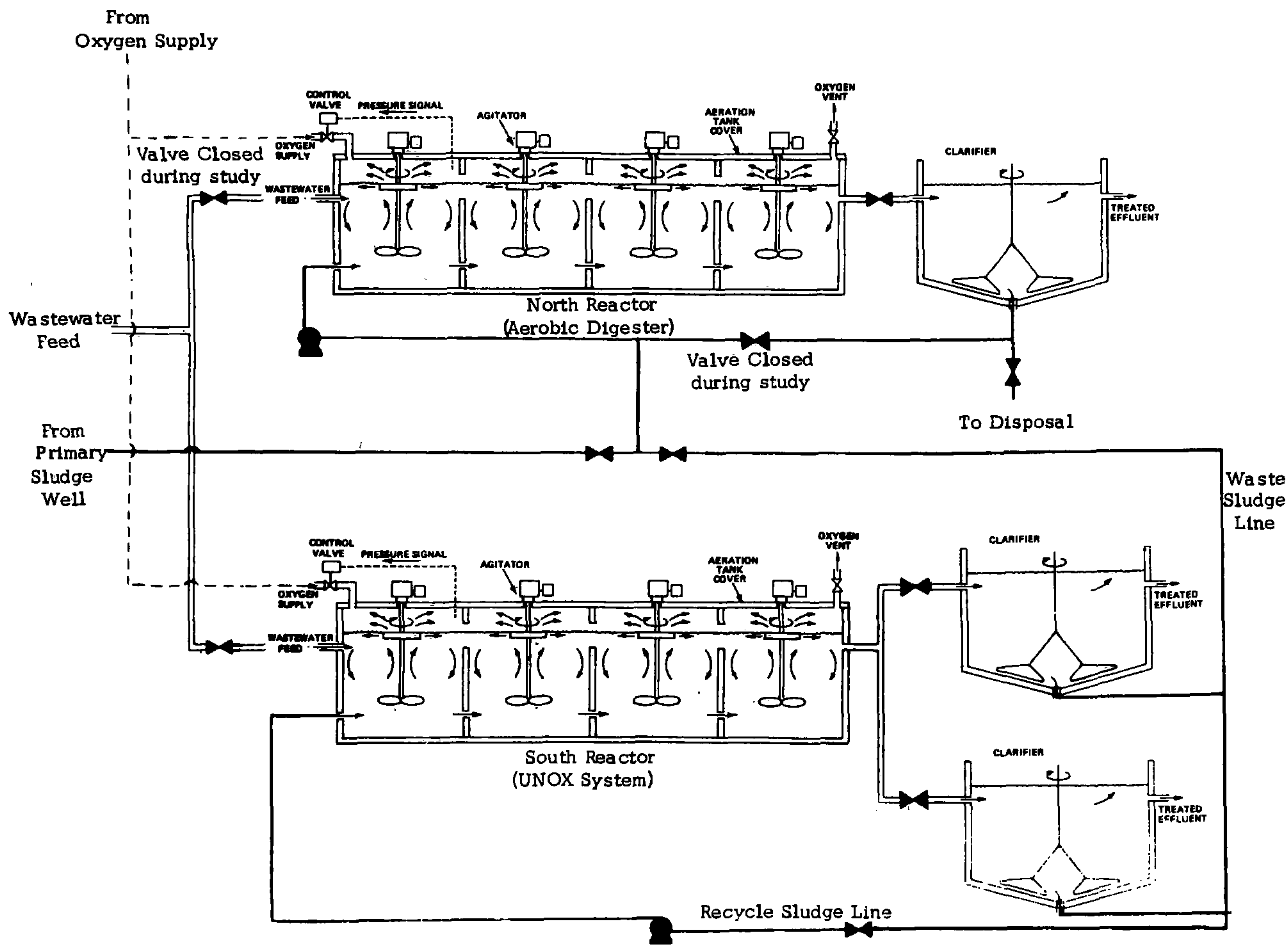

Figure 1: UNOX System at Speedway, Indiana (Schematic).

activated sludge was fed to the four stage digester system daily over a nine hour period. During operations with both primary and secondary sludges, the primary sludge was pumped to the digestion unit twice each day—Monday through Friday. The digested sludge was stored in clarifier number 3 which was periodically pumped to Speedway's sludge disposal system.

Daily samples of feed sludge, Stage 1 contents, and Stage 4 contents were taken and analyzed by Speedway Treatment Plant personnel for total suspended solids (TSS), volatile suspended solids (VSS), and chemical oxygen demand (COD). Daily measurements of temperature, dissolved oxygen (D.O.), gas flows, and gas purities were also obtained on Stages 1 and 4. The average ambient temperature was also recorded daily. Oxygen uptake rates, settling tests and pH measurements were performed three times each week. Weekly composite samples from Stages 1 and 4 were also analyzed for total Kjeldahl nitrogen (TKN), ammonia (NH_3), and total phosphorus. The data were collected for each phase of operation only after the digester had been run for at least one retention time (SRT) to insure that the digester was properly acclimated.

RESULTS AND DISCUSSION

The Speedway aerobic digestion studies were divided into two phases. During Phase I (9/20/72 - 11/5/72) the digester was fed waste activated sludge only. Phase II (11/7/72 - 12/20/72) was operated with a mixture of primary and secondary sludge.

Table 1 contains the characteristics of the sludges fed to the aerobic digesters in this study. The TSS of the secondary sludge ranged from 1.8 to 2.8 percent, values fairly typical of sludges from a UNOX System treating primary effluent. The TSS of the primary sludge ranged from four to six percent so that the combined feed to the digester during Phase II averaged approximately 3.0 percent

TABLE 1
Characteristics of Sludges Fed to Digesters

	PHASE I		PHASE II			
	UNOX System Sludge		UNOX System Sludge		Primary Sludge	
	Overall Average	Range	Overall Average	Range	Overall Average	Range
Temperature, °F	67.0	62-74.0	60.0	55-65	60.0	57-65
pH	6.6	6.2-6.8	6.7	6.2-6.9	6.8	6.4-7.2
COD, 10,000 mg/l	2.98	2.50-3.70	3.16	2.9-3.6	6.27	4.2-8.2
TSS, 10,000 mg/l	2.14	1.82-2.60	2.41	2.0-2.74	4.74	3.8-6.0
VSS, 10,000 mg/l	1.64	1.40-1.90	1.69	1.48-1.90	2.91	2.4-3.9
Alkalinity, mg/l as $CaCO_3$*	—	---	2250	2220-2940	3690	2070-4830

*For the week ending 12/17/72.

total suspended solids with a volatile fraction of 0.66.

General operating experience gained from this study included the ease at which the process could be controlled. It required only one retention time for the solids in the digester to build to steady state concentrations. The operation of the digester did prove to be very sensitive to the D.O. level maintained in the reactor. A rapid increase in the rate of digestion was qualitatively observed when the D.O. of the reactor was increased from < 1.0mg/1 to values greater than 2 mg/1. However, maintaining D.O. concentrations of 2 mg/1 required drastic decreases in the system oxygen utilization to increase the mass transfer capabilities of the existing dissolution equipment which was not designed for aerobic digestion. Since there was insufficient oxygen production capability to sustain prolonged operation at reduced digester oxygen utilization, the dependency of K_D on D.O. concentration was not developed in detail.

Table 2 presents the average operating conditions observed during each of the phases of operation. Because the oxygenation facility used as the aerobic digester was not specifically designed for this purpose, problems were encountered with respect to the staging characteristics of the unit. The fact that the TSS values for Stages 1 and 4 are similar during both phases of operation is a result of back mixing. The interstage openings were designed for 3.75 mgd of continuous plant influent flow plus recycle. The 13,000 to 21,000 gpd feed on a semi-batch basis was not sufficient to permit the system to operate as a four stage unit. The actual systems's performance could have been that of a completely mixed tank for Phase I and a two or three stage unit (because of the increased feed flow) for Phase II.

Some of the interesting data contained in Table 2 are the temperatures of the reactor. In Phase I the digester maintained an average temperature of 91°F even though the feed temperature was 67°F and ambient air was less than 45°F. During Phase II temperatures as high as 91°F were obtained in the digester even though the feed and ambient temperatures averaged less than 61°F and 28°F

TABLE 2
Average Operating Conditions for the Oxygenated Aerobic Digestion System at Speedway, Indiana

	Phase I	Phase II (57% UNOX System Sludge by Wt.)
Flow Rate, gpd	14,250	20,700
Feed Temperature, °F	67	60.8
Retention Time, days	16.3	11.6
Stage 1		
TSS, mg/l	12,800	20,700
VSS, mg/l	9,080	12,900
% VSS	70.9	62.3
Temp., °F	90.8	88.2
D.O., mg/l	1.6	0.55
Stage 4		
TSS, mg/l	13,100	18,300
VSS, mg/l	9,220	11,500
% VSS	70.4	62.8
Temp., °F	91.1	88.8
D.O., mg/l	1.2	0.55
Average Ambient Temperature, °F	45.5	28
Solids Loading Rate # VSS/Day Ft^3	0.063	0.106

respectively. This ability to maintain high temperatures during winter conditions is a result of the heat liberated by the microorganisms through endogenous respiration. No external source of heat was utilized in these experiments. The increased temperature rise in Phase II was probably a result of increased heat generation due to the higher loading and the higher VSS concentration of the feed.

Table 3* reports the volatile solids reduction data obtained during this study. Overall VSS reductions of 43.9 and 43.0 percent were achieved during Phases I and II respectively. Insufficient analytical data were generated to enable a determination of the average biodegradable fraction of the influent volatile solids. As a result, an accurate appraisal of the digester performance in terms of the approach to complete digestion was not possible. Qualitatively however, the digested sludge appeared very stable. On many occasions the digested sludge was stored in Clarifier No. 3 for extended periods of time (approximately 15 days) with no significant odor problems. Notwithstanding this lack of analytical quantification however, a theoretical determination of the percent approach to complete digestion is presented below.

The kinetic model presented earlier can be applied to the data collected at Speedway, by solving equation (3) for BVSS and thus obtaining:

$$\frac{BVSS\ t = t}{BVSS\ t = O} = \frac{1}{1 + K_D\ t_Q} \qquad (5)$$

Applying equation (5) to each stage of a multistaged system and combining into a single expression results in equation (6)

$$BVSS_t = t = BVSS_t = O \left(\frac{1}{1 + K_D\ t_{Q/n}} \right)^n \qquad (6)$$

where n equals the number of stages to be considered.

To properly utilize equation (6) the effect of temperature on the K_D constant must be established. Essentially the Θ value of equation (4) must be obtained for the sludge in question. Unfortunately this was not done during the Speedway test. However, Figure 2 does contain a generalized correlation of data obtained from the literature[1,7] as well as tests performed on similar sludges at Union Carbide's laboratories[6]. Applying the corresponding K_D value from Figure 2 to the data obtained for VSS reduction it was anticipated that the actual number of digestion stages could be calculated for various BVSS fractions in the feed. Figures 3 and 4 present a graphical display of this attempt for Phases I and II, respectively.

For example, equation (6) would predict a BVSS reduction of 78 percent in a four stage digester operating under the conditions observed at Speedway during Phase II. Thus, if 48 percent of the influent VSS were biodegradable the corresponding VSS fraction degraded would be approximately 37 percent. Point "A", shown on Figure 4, represents this reduction of VSS and BVSS for a theoretical four stage digester. In the Speedway digester, as mentioned earlier, backmixing was a problem due to the equipment used in this study. This high degree of backmixing encountered leads one to assume that the number of theoretical stages was significantly less than the actual number (four). If the number of theoretical

TABLE 3
Summary of Volatile Solids Reduction Speedway High Purity Oxygen Aerobic Digestion Experiments

Phase	*Feed Sludge Type*	*Retention Time, Days*	*Digester Temp. °C*	*Volatile Solids Loading Rate #VSS/Day/Ft³*	*% VSS Reduction*
I	UNOX System WAS*	16.3	32.8	0.0629	43.9
II	UNOX System WAS* & Primary	11.6	31.6	0.106	43.0

*WAS = Waste Activated Sludge.

*Tables 4 & 5 contain weekly summaries of the data obtained during each phase of this study.

TABLE 4
Summary of Aerobic Digestion Data (Speedway, Ind.) for Phase I (UNOX System Sludge Only)

Starting Date: 9/20/72 Week Ending Measured Data	*10/15/72*	*10/22/72*	*10/29/72*	*11/5/72*	*Average*
Feed					
Flow Rate, GPD	15,000	13,400	14,300	14,300	14,250
TSS, mg/l	22,100	21,100	20,200	22,000	21,400
VSS, mg/l	16,700	16,400	15,900	16,700	16,400
% VSS	75.6	77.7	78.7	75.9	76.6
Temp., °F	72	66	66	65	67
Stage 1					
TSS, mg/l	12,900	11,400	13,000	13,800	12,800
VSS, mg/l	8,900	7,890	9,240	10,300	9,080
% VSS	69.0	69.2	71.0	75.0	70.9
Temp., °F	92.5	93.4	90.3	87.0	90.8
D.O.[a]	1.9	2.0	1.2	1.2	1.6
O_2 Purity, %	51.9	48.6	41.7	38.0	45.0
CO_2 Purity, %	>20	>20	>20	42.7	42.7
Stage 4					
TSS, mg/l	13,800	11,300	13,600	13,700	13,100
VSS, mg/l	9,930	7,740	9,400	9,820	9,220
% VSS	72.0	68.5	69.0	72.0	70.4
Temp., °F	93.0	93.9	90.4	87.0	91.1
D.O.[a]	1.4	1.5	0.67	1.3	1.2
O_2 Purity, %	40.0	40.7	36	31.0	36.9
CO_2 Purity, %	>20	>20	>20	42.7	42.7
ISR, ft/hr.	1.22	1.89	0.9	0.75	1.19
Miscellaneous					
Average Ambient Temp., °F.	47	43	45	47	45.5
O_2 Feed, cfd		19,000	19,700	22,000	20,200
O_2 Purity in feed, %		≈90	≈90	≈90	≈90
Vent Gas Flow, cfd		13,200	15,400	17,400	15,300
Calculated Data					
Solids Reduction					
Retention time, days	15.5	17.3	16.2	16.2	16.3
% VSS Digested	40.8	52.7	40.7	41.2	43.9
% TSS Reduction	37.3	46.6	32.5	37.8	38.6
Loading Rate, #VSS/day/ft^3	.0674	0.0590	.0609	.0642	.0629
Oxygen Consumption					
O_2 Consumption; lbs/lb VSS		1.06	1.34	1.48	1.29
O_2 Utilization, %		72	70	74	72
CO_2 Generation, lbs/lb O_2 Used				(0.70)	(.70)

[a]4 Ft. off bottom.

stages at Speedway during Phase II was two, as suggested earlier, Figure 4 would indicate that more than half of the influent VSS was biodegradable.

The COD reduction capabilities of the process were also measured at Speedway. Average COD reductions of 51.4 and 56.9 percent were obtained for the respective phases of operation. Little information is presented in the literature with respect to the amount of COD reduction expected through aerobic digestion. This is believed due to the prime interest of investigators in VSS reduction and the difficulties associated with measuring the parameter, e.g., the total COD ranged from 20,000 80,000 mg/l for the Speedway studies.

The O_2 consumption data obtained during this test were established by making a gas phase O_2 balance around the digester. The average O_2 consumption ratio of 1.29 and 1.85 lbs. O_2/lb. VSS reduced were obtained for the waste UNOX sludge and the UNOX primary mixture, respectively. These values are very close to those reported in the literature for similar sludges. The increased O_2 requirement for the primary sludge is believed to be due to a large quantity of organic substrate that is metabolized in the digester, producing cellular material which is then digested.

The O_2 utilization values for both phases averaged approximately 70 percent. This low value was due to the inherently high CO_2 production of the digestion process, the inability of the existing system to maintain a high D.O. (D.O. > 1.0 mg/l) at lower oxygen purities, and the poor gas staging characteristics encountered at the low gas flow rates required by the process.

TABLE 5
Summary of Aerobic Digestion Data (Speedway, Ind.) for Phase II (Mixture of UNOX System & Primary Sludges)

Starting Date: 11/7/72 *Week Ending* *Measured Data*	*11/26/72*	*12/3/72*	*12/10/72*	*12/17/72*	*Average*
Feed (% UNOX System Sludge by wt.)[b]	54.6	55.4	57.9	60.0	57.0
Flow Rate, GPD	18,600	20,700	20,100	20,700	20,700
TSS, mg/l	30,800	29,200	31,700	30,900	30,600
VSS, mg/l	20,800	18,900	20,700	20,300	20,200
% VSS	67.2	64.9	65.4	65.7	66.0
Temp., °F	63.0	62.0	60.0	58.0	60.8
Stage 1					
TSS, mg/l	20,900	20,800	21,600	19,500	20,700
VSS, mg/l	13,600	12,900	13,200	12,000	12,900
% VSS	65	62	61	61	62.3
Temp., °F	88	88	91	86	88.2
D.O.	.7	.6	0.3	0.6	.55
O_2 Purity, %	59	62	66	57	61.0
CO_2 Purity, %	26		19	20	21.7
Stage 4					
TSS, mg/l	18,900	18,200	18,400	17,800	18,300
VSS, mg/l	12,300	11,400	11,300	11,000	11,500
% VSS	65.0	62.0	61.0	61.8	62.8
Temp., °F	88.0	90.0	91.0	86.0	88.8
D.O. [a]	0.6	0.6	0.4	0.6	0.55
O_2 Purity, %	50	53	58.8	48.0	52.4
CO_2 Purity, %	37		30	29	32.0
ISR, ft/hr.	0.37	0.5	0.46	0.86	.55
Miscellaneous					
Average Ambient Temp., °F	35	35	25	18	28
O_2 Feed, cfd	42,900	50,500	59,700	54,400	51,900
O_2 Purity in Feed, %	≈90	≈90	≈93	≈93	≈91
Vent Gas Flow, cfd				36,900	36,900
Calculated Data					
Solids Reduction					
Retention time, days	12.5	11.2	11.5	11.2	11.6
% VSS Digested	40.7	39.8	45.4	45.9	43.0
% TSS Reduction	38.7	36.1	41.9	42.5	39.8
Solids Loading Rate, #VSS/day/ft³	0.0967	0.103	0.112	0.113	0.106
Oxygen Consumption					
O_2 Consumption, lbs/lb VSS	1.92	1.89	1.90	1.78	1.87
O_2 Utilization, %	65	65	65	67.8	66
CO_2 Generation, lbs/lb O_2 Used				(0.5)	(0.5)

[a] 4 Ft. off bottom
[b] Based on TSS

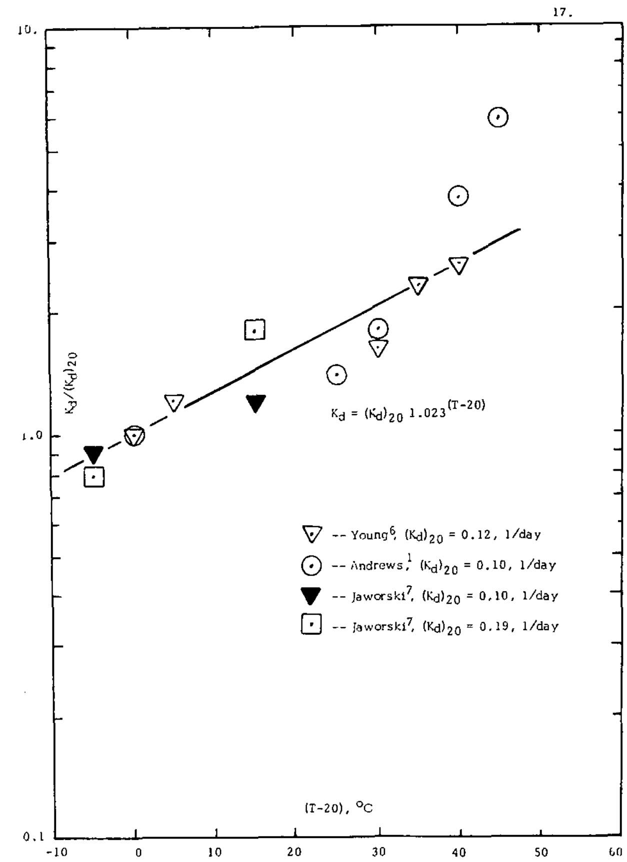

Figure 2: Effect of Temperature on the Decay Constant, Kd.

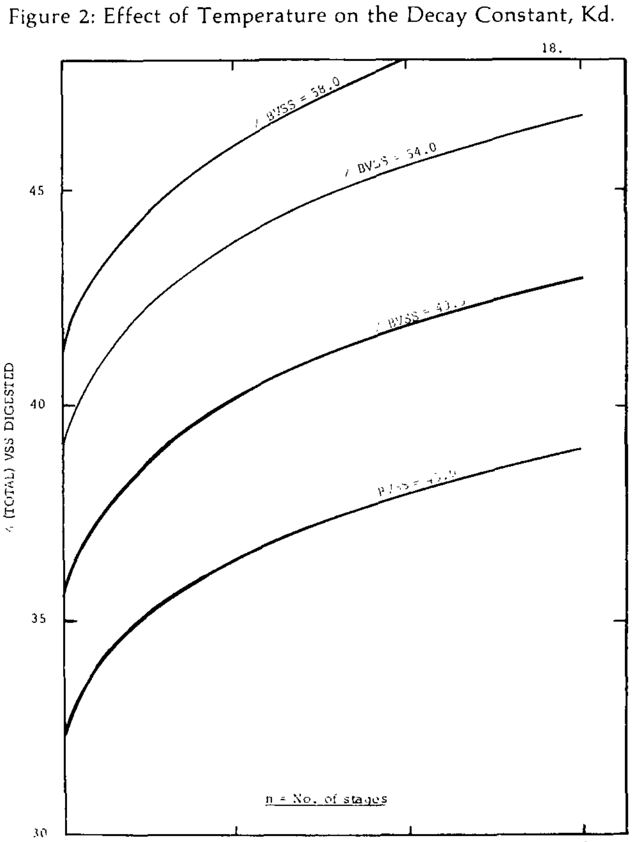

Figure 3: Speedway Aerobic Digestion, Phase I, Percent VSS Digested Vs. Number of Stages.

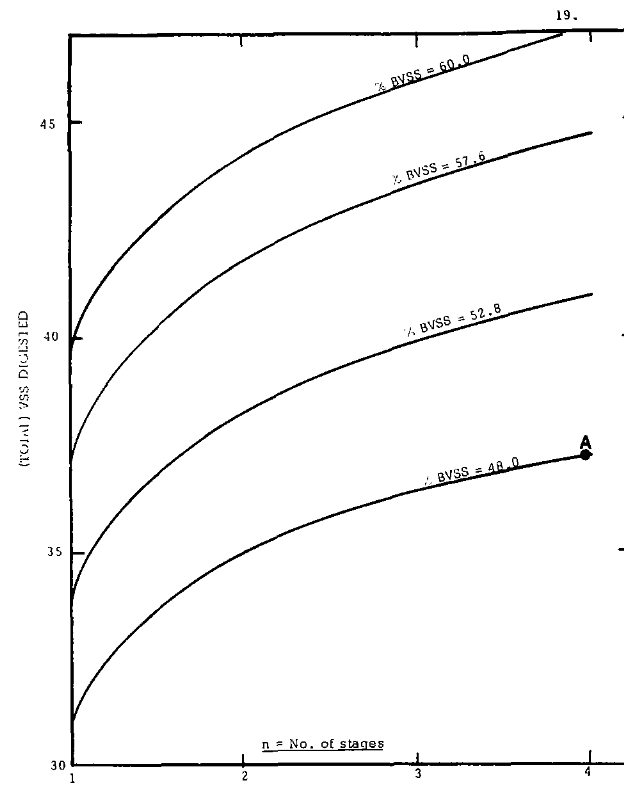

Figure 4: Speedway Aerobic Digestion, Phase II, Percent VSS Digested Vs. Number of Stages.

Because of the poor method of CO_2 measurement available to the operators at Speedway, the respiration coefficient obtained for the process was much lower than the 1.0 or 0.7 moles CO_2/mole O_2 predicted through equations (1) and (2), respectively. A value of 0.5 moles CO_2/mole O_2 was obtained using *Draga* tubes for CO_2 measurements on grab samples of gas.

A limited amount of settling and thickening data was obtained during this program. All the data were obtained using a one liter graduate cylinder stirred at a rate of one RPM. This data is plotted in Figure 5 and demonstrates that the settling velocities of the aerobically digested sludge at Speedway, Indiana fall within the range of those observed for oxygen activated sludge.

Finally, the weekly composite samples obtained from Stage 4 of the digester for nutrient analyses indicated that:

(a) there was hardly any nitrification occurring at the temperatures observed
(b) the NH_3-N concentration was increased due to nitrogen solubilization from 50 mg/1 in the feed to 100-120 mg/1 in the digester supernatant, and
(c) the soluble phosphorus concentration increased from 60 mg/1 to 100 mg/1.

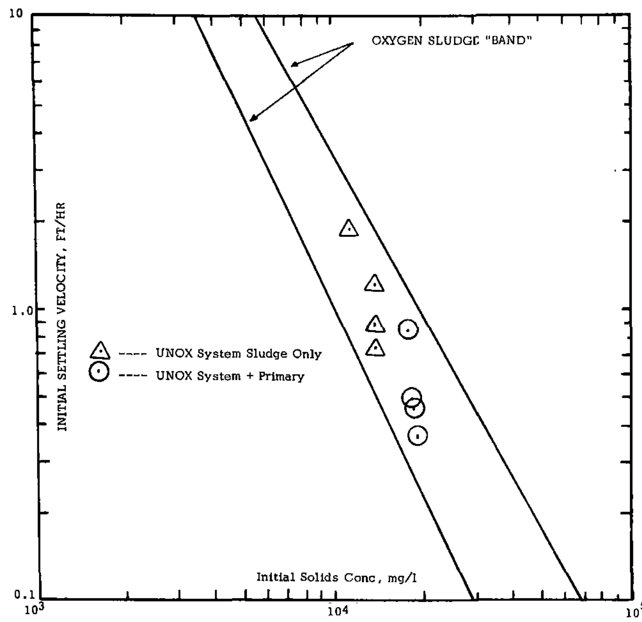

Figure 5: Aerobic Digested Sludge Settling Data.

Economics

The test work done at Speedway, as previously mentioned, was accomplished using tankage that was specifically designed to operate as a secondary oxygen activated sludge system. The relatively small liquid and gas flows through the system during the aerobic digestion study resulted in a number of inefficient operating characteristics. These inefficiencies, of course, resulted in very distorted system economics. Therefore, based on the process information collected during this study, an aerobic digestion system was designed (but has not been installed) to treat the primary and waste activated sludge generated by the Speedway facility at design year operating conditions. The economics presented herein therefore are considered typical oxygen aerobic digestion costs for small scale low strength waste municipal facilities with primary treatment.

The major unit operations at the Speedway, Indiana facility were designed for influent hydraulic conditions of 7.5 MGD. The existing oxygen generator is a four tons per day pressure swing adsorption type unit and the dissolution system is as described earlier. Since the plant influent flow observed during the aerobic digestion studies was only slightly more than half this design flow, extrapolation of some of the plant influent conditions was necessary to insure a properly designed and integrated aerobic digester. Therefore, for this analysis it was assumed that the primary and secondary operating characteristics are as shown on Table 6. These characteristics are consistent with the anticipated design year hydraulic conditions and the wastewater character presently observed at the Speedway, Indiana facility.

The data shown on Table 6 were used as the basis for the aerobic digestion system design. The aerobic digester therefore has been designed for an average waste sludge volume of 31,840 gallons per day with a total suspended solids concentration of approximately 3.3 percent. The design temperature of the feed to the aerobic digester was assumed as 20°C with the feed stream dry solids content being composed of 55 percent waste primary sludge and 45 percent waste secondary sludge. This composition is slightly different than the feed characteristics observed during the digestion studies because not all of the primary waste sludge generated during the study was fed to the aerobic digester. Therefore, based on the plant influent conditions and the secondary system sludge production characteristics shown in Table 6, the 55:45 primary to secondary waste sludge ratio was determined.

A schematic layout of the Speedway plant with an incorporated aerobic digester is presented in Figure 6. The aerobic digester will be a single train

TABLE 6
Design Year Operating Characteristics of the Primary and UNOX Systems at Speedway, Indiana

Influent Conditions:	
Flow	7.5 mgd
BOD_5	175 mg/l
COD	350 mg/l
SS	175 mg/l
pH	- 7
Temp.	= 20°C
Primary System Operating Characteristics:	
Underflow TSS	= 4.75%
Underflow VSS	= 2.9%
Dry Solids Wasted	= 4690 lbs/day
Total Waste Volume	= 11,840 gallons/day
UNOX System Operating Characteristics:	
Retention Time	1.48 hrs.
Biomass Loading	0.38 lbs. BOD_5/lb. MLVSS/day
Underflow TSS	2.4%
Underflow VSS	1.69%
Dry Solids Wasted	3915 lbs/day
Total Waste Volume	= 20,000 gpd

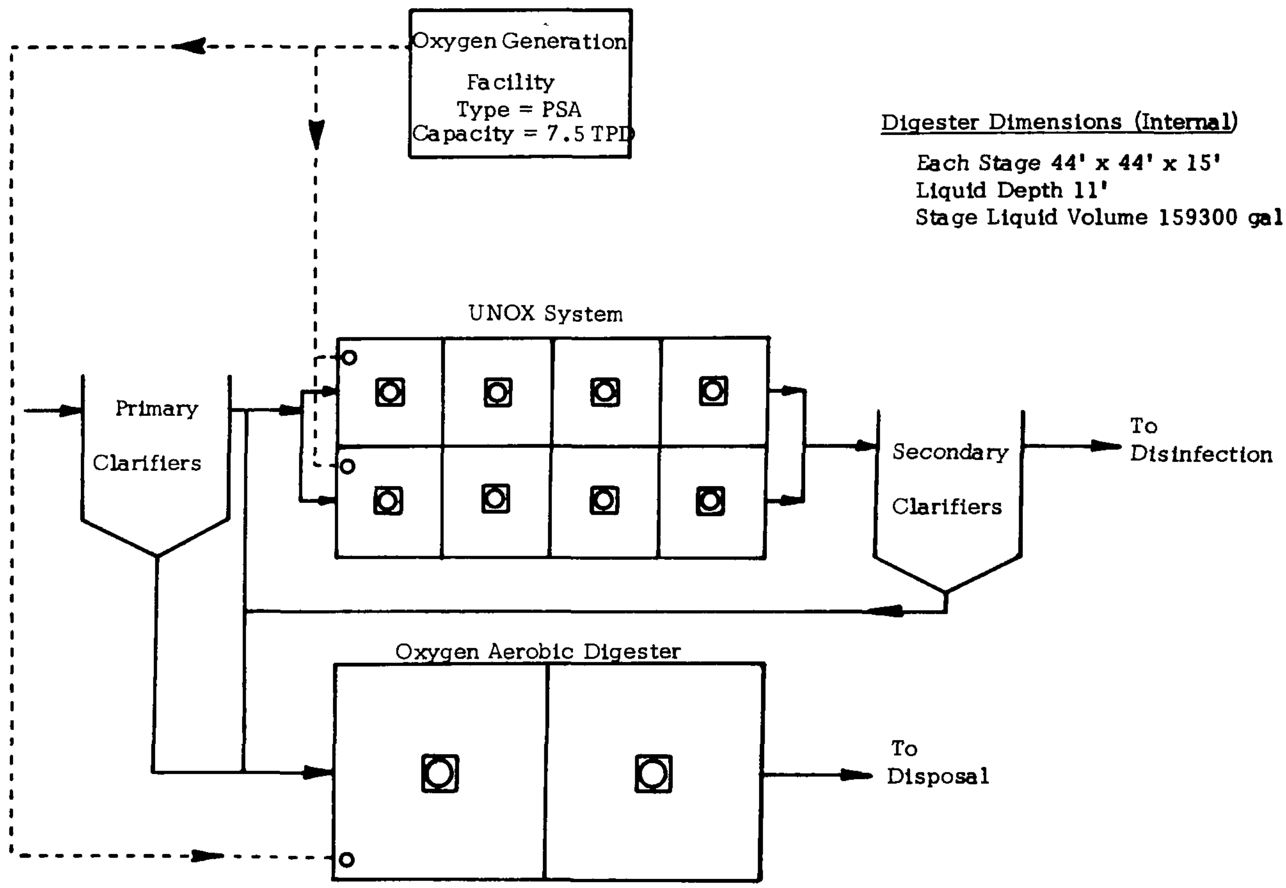

Figure 6: Speedway, Indiana Plant Layout with Oxygen Aerobic Digestion (Schematic).

two stage system with a liquid volume of approximately 318,600 gallons. Each stage has internal (excluding wall, bottom, or cover thickness allowances) dimensions of 44 ft.×44 ft.×15ft. with a liquid depth of 11 feet. In ground tankage was specified to utilize the thermal insulating capacity of the ground. The design was also based on the *worst case* average ambient air temperatures expected during the winter season. Therefore, summertime operating temperatures may be somewhat higher. The two stage design was selected rather than a three or four stage system because of both operating and economic advantages. The relatively large surface dimensions of each stage facilitate adequate mixing and mass transfer at the specified liquid depth. Increasing the number of stages would necessarily result in decreasing the liquid depth in each stage (due to the decreased surface dimensions of each stage) to insure the maintenance of adequate mixing and mass transfer. Furthermore the heat losses of the two stage system are less than the multistage systems because of the reduced exposed surface area to volume ratio. The decreased heat loss, of course, results in the potential for higher system operating temperatures.

The two stage system also has economic advantages since it requires fewer interstage baffles and fewer mechanical aerators than the multistage systems. Capital investment savings can therefore be realized because less concrete is required for the tankage, and advantage can be taken of the "economy of scale" costs of the larger (but fewer) mechanical aerators required. The combination of the operating and economic advantages inherent in the two stage design indicated that this was the optimum configuration for this particular location.

The retention time of this system at design conditions is ten days. Based on the aerobic digestion studies conducted at Speedway, this system will achieve approximately a 44 percent reduction of VSS at a temperature of 36°C. The system is designed to maintain a D.O. concentration of 2 mg/l at an oxygen utilization of between 65 and 70 percent. The oxygen requirement, based on the consumption characteristics observed during the digestion studies, is 3.5 tons per day.

Each digester stage is equipped with a mechanical aerator having a submerged, supplemental mixing device. Table 7 shows the installed and operating energy requirements for mixing and mass transfer at design conditions. Also included on Table 7 is the power necessary to generate the required oxygen. To reflect accurate system economics the oxygen generator was sized to satisfy the oxygen requirements of both the UNOX System and the aerobic digestion system (7.5 tons per day). The power, capital investment, and operating costs of oxygen production for the aerobic digestion system were then taken as a fraction (0.46) of the power and costs associated with oxygen production for the entire Speedway treatment facility.

The installed cost of the Speedway aerobic digestion system is estimated to be $510,000. This cost includes the dissolution equipment, tankage, oxygen generation equipment, and all instrumentation required for a completely integrated, fail safe unit operation, in addition to monies for the installation and startup of all the above equipment. The costs of unit operations (e.g., thickeners, vacuum filtration, centrifugation, etc.) following the aerobic digester have not been included in the cost of the aerobic digestion system because their use is a function of the ultimate sludge disposal objectives.

Amortizing the capital investment at a six percent interest rate over the 25 year economic life of the plant and assuming a power cost of 1.3 cents per KWH, the annual cost of aerobically digesting the Speedway waste sludge is $53,400. This yearly figure represents an average cost of $34.00 per ton of dry solids treated.

It should be noted that these costs are specific to the Speedway facility. Normally an aerobic digester is integrated with a UNOX System design in the most cost effective manner by considering, among other things, (1) the overall effective transfer efficiencies of each unit operation, (2) the relative quantities of primary and secondary sludges to be treated, and (3) the degree of treatment required from each unit operation. Since the original Speedway facility was designed without aerobic digestion, this economic optimization procedure was somewhat restricted.

Furthermore, these costs do not reflect many of the intrinsic advantages of an oxygen aerobic digester. Since an oxygen digester is covered, the aerating gas is vented through a single vent stack; thus effective odor control is achieved and the biological aerosol problem typical of air aerobic digesters is eliminated. The covered tankage operating at elevated temperatures also eliminates the freezing problem often encountered in northern climates. Also, the covered digester acts essentially as a respirometer, providing real time response to the sludge loads placed on it. It is therefore possible to automate the oxygen production unit to respond to these changes in sludge load, thereby causing the system to use only the appropriate power for oxygen generation commensurate with the sludge loading being processed. Therefore, although the actual costs of oxygen aerobic digestion are dependent upon individual circumstances, the costs presented herein can be considered representative for small scale municipal facilities with primary treatment.

TABLE 7
Aerobic Digester Design Criteria Summary

Design Criteria:		
Flow, gpd		31,840
Total Suspended Solids, mg/l		33,000
, %		3.3
Volatile Suspended Solids, mg/l		21,000
, %		2.1
Feed Stream Temperature, °C		20
Ambient Air Temperature, °C		-2
pH		6.8
Operating Characteristics:		
Retention Time, days		10
Operating Temperature, °C		36
VSS Reduction, %		44
Average D.O., mg/l		2
Oxygen Utilization, %		65-70
Oxygen Required, tons/day		3.5
Energy Requirements:		
	Operating Power, BHp	*Installed Power, Hp*
Oxygen Dissolution	67	80
Oxygen Generation	88	--
Miscellaneous	4	--
Total	159	--

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APPENDIX A Nomenclature

ΔH_m	Energy Utilized for cell maintenance (BTU/lb. of VSS)
ΔH_c	Energy Released through combustion (BTU/lb. of VSS digested)
$t_Q = t$	Retention Time of digestion, (days)
X_o	VSS of sludge leaving digester, (mg/1)
K_D	Endogenous rate, (1/day)
Ki	(Fractional) efficiency of energy transfer by biological reaction through heterogeneous microorganisms
X_i	VSS of sludge fed to the digester, (mg/1)
fs	Fraction of total VSS digested
BVSS	Biodegradable Volatile Suspended Solids, (mg/1)
K_{D20}	Endogenous rate at 20°C, (1/day)
T	Temperature in degrees centrigrade
Θ	Temperature coefficient
n	Number of stages in the digester
D.O.	Dissolved Oxygen Concentration
P.B.T.	Pitched Blade Turbine

SLUDGE DEWATERING

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ABSTRACT

Commencing in April, 1970, an extensive sludge dewatering investigation was undertaken at the Los Angeles County Sanitation Districts' 380 mgd Joint Water Pollution Control Plant. Discharge requirements set by the Los Angeles Regional Water Quality Control Board necessitated that a minimum of 95 percent of the suspended solids in the digested sludge be removed. Various combinations of sludge conditioning (polymer, chemical, thermal) and sludge dewatering (centrifugation, pressure filtration, vacuum filtration) were examined, the results of which indicated that five conditioning-dewatering systems were capable of meeting the required effluent quality. An economic evaluation was made of each system, from which a two stage centrifugation system was found to be the alternative of lowest cost. The system consisted of the existing horizontal scroll centrifuges and imperforate bowl basket centrifuges with polymer conditioning for the second stage basket machines. The composite sludge cake from the system will be hauled to a sanitary landfill for ultimate disposal.

INTRODUCTION

One of the most difficult problems in wastewater treatment is the processing and disposal of sludge, and recently the complexity of the problem has been magnified by increasingly stringent quality standards for treated wastewaters. Additionally, in many instances expanding urban development has limited the land area available for sludge disposal and has necessitated the dewatering of sludge prior to its ultimate disposal. In the mid 1950's the Los Angeles County Sanitation Districts recognized this problem and installed horizontal scroll centrifuges for sludge dewatering at its Joint Water Pollution Control Plant (JWPCP) a 380 mgd primary treatment facility located in the city of Carson, California. Figure 1 shows a schematic of the JWPCP treatment and disposal system. In addition to municipal and industrial wastes entering the plant through several trunk sewers, five water renovation plants located upstream from the JWPCP discharge raw and waste activated sludge into the tributary trunk lines. Basically, the treatment plant consists of primary sedimentation, anaerobic digestion of the settled solids and horizontal scroll centrifugation (30 percent S. S. recovery) of the digested sludge.

The primary effluent from the sedimentation tanks, along with centrate from sludge dewatering, is discharged to the Pacific Ocean at White's Point through a series of submarine outfalls using multiport diffusers at a distance of about two miles offshore and a depth of 150 to 200 feet. The effluent is chlorinated to comply with ocean bacteriological standards.

The dewatered cake from the centrifuges is spread on land adjacent to the dewatering site for open air drying, aided by mechanical turning of the sludge on the drying beds. The dried sludge is collected from the beds and sold to a local fertilizer manufacturer for use as a soil conditioner.

Over an extensive time period, the monitoring of ocean waters surrounding the JWPCP outfall system identified settleable and floating material which were attributable to centrifuge centrate discharge along with primary effluent. In early 1970 a major research effort was initiated by the Districts, the purpose of which was to investigate methods for improving solids capture during sludge dewatering. In September of 1970 the Los Angeles Regional Water Quality Control Board established new effluent standards for the JWPCP. Compliance with the new standards required a major supplementation to the existing treatment facilities. Additional primary sedimentation capacity would be needed to bring about greater suspended solids removal from the raw sewage. Moreover, the new standards mandated a criterion for a sludge dewatering system which would be capable of recovering at least 95 percent of the suspended material in the digested sludge.

The sludge dewatering research program involved a comprehensive review of existing technology and a pilot plant evaluation of those systems having documented process performance. These systems included centrifuges, vacuum filters and pressure filters. Because of the potential economics offered by a dewatering scheme that would use the existing horizontal scroll centrifuges, each pilot dewatering system was evaluated with respect to its ability to dewater centrate from the existing centrifuges as well as digested sludge. The major criterion used in evaluating a dewatering system was an effluent suspended solids of less than 1,500 mg/1.

Processes for Sludge Conditioning

Initial testing of the pilot systems indicated that dewatering without some form of prior conditioning of the sludge failed to produce the desired solids recovery. Four types of sludge conditioning were evaluated: thermal conditioning, conditioning with cationic polymers, chemical conditionng with ferric chloride and/or lime, and fly ash conditioning.

In the thermal conditioning process, sludge is heated under pressure to a temperature normally greater than 310°F. At these temperatures and pressures bound water associated with the solid matter in the sludge is released, the sludge is more easily dewatered and dryer cakes should be obtained. To evaluate the process on the JWPCP sludge a 200 gph pilot unit was procured.

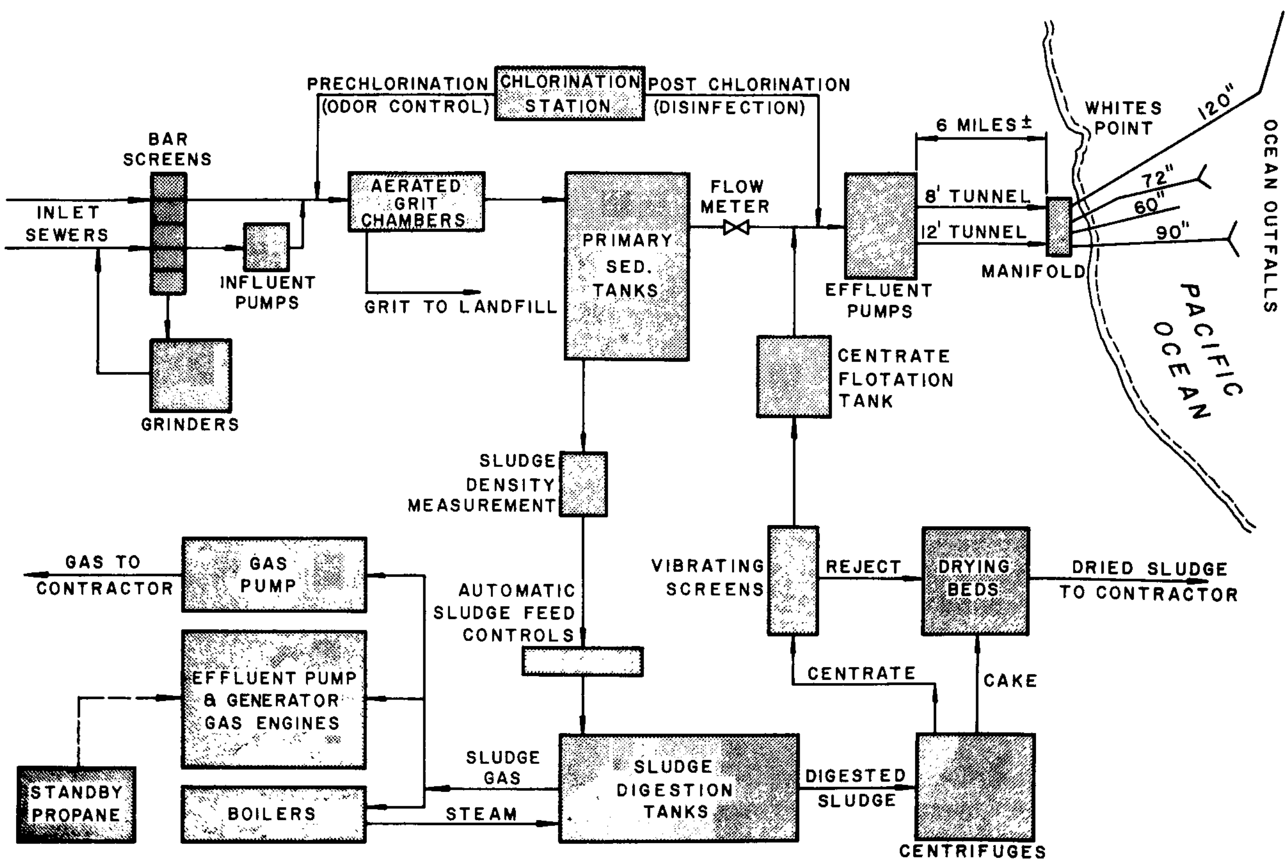

Figure 1: Schematic Diagram of the Joint Water Pollution Control Plant.

The initial investigations with the heat treatment system were directed towards determining the optimum temperature—detention time relationship for the digested sludge. In this determination it was important to note that the thermal conditioning process results in the solubilization of a significant amount of the suspended material in the sludge. To minimize the solubilization of such organic material, and thus minimize the soluble oxygen demand, it is desirable to operate a thermal conditioning system at the lowest possible temperature. With cognizance of this phenomenon, optimum conditions in the operation of the unit were defined as those that resulted in the lowest suspended solids concentration after dewatering. Time-temperature tests were conducted at two sludge detention times—30 and 40 minutes and at temperatures ranging from 165° to 201°C (330° to 395°F). Results of these tests indicated that at the 30 minute detention period, the supernatant suspended solids from a one hour laboratory settling test were reduced from approximately 6,000 mg/1 to 3,500 mg/1 by increasing the temperature from 165° to 182°C (330° to 360°F). The supernatant suspended solids concentration was not further reduced by temperature increased above 182°C (360°F). A similar trend occurred at a sludge detention time of 40 minutes, the differences being that the minimum supernatant suspended solids level was reached at a temperature of 177°C (350°F), and the supernatant suspended solids concentration at that temperature was approximately 3,000 mg/1. It was concluded from the testing that the optimum thermal conditioning temperature for the digested sludge was 177°C (350°F) at a detention time of 40 minutes. Under these operating conditions the suspended solids concentration of the digested sludge decreased from approximately 40,000 mg/1 to 30,000 mg/1 following thermal conditioning. This decrease was thought to be the result of dilution water added by the steam required to raise the temperature of the sludge and in part by the solubilization of suspended material.

Once the optimum temperature-detention time relationship was developed, a pilot gravity thickener was evaluated on the heat treated sludge. Detention times ranging up to two hours were investigated, along with overflow rates varying from 200 to 650 gpd/sq.ft. From an evaluation of the thickener, it was concluded that supernatant suspended solids of approximately 3,700 mg/1 could be obtained by gravity thickening of thermally-conditioned sludge for one hour at an overflow rate of 225 gpd/sq.ft. The corresponding underflow solids concentration was between nine and ten percent. Further dewatering investigations indicated that the combined process of thermal conditioning and gravity thickening resulted in an effective pretreatment system.

Polymer conditioning was used in conjunction with centrifugation, vacuum filtration and pressure filtration, while chemical conditioning was investigated for the vacuum filtration and pressure filtration processes. Fly ash conditioning was evaluated solely in conjunction with pressure filtration. The effectiveness of all of the conditioning agents is discussed in the subsequent section regarding dewatering processes.

Sludge Dewatering

Centrifugation: Horizontal Scroll

Horizontal scroll centrifugation studies were directed towards the processing of the JWPCP digested sludge through the existing centrifuges. However, studies on the centrifugal dewatering of heat-conditioned digested sludge were also conducted with a pilot scale (six inch diameter) horizontal scroll centrifuge.

The evaluation of the *base* performance of the existing centrifuges was carried out in a manner which enabled the effect of variations in sludge feed rate and bowl pool depth to be independently assessed. Considered in this respect were primary digested sludge feed rates between 200 and 400 gpm, and pool depths between 1.0 and 3.5 inches. The rotational speed of the bowl was held constant at 1300 rpm. The differential speed, i.e., the speed difference between the bowl and scroll, remained fixed at 15.3 rpm. The bowl speed was held constant at 1300 rpm because previous experience had shown that the maintenance associated with higher speeds was excessive. Figure 2 shows the effect of pool depth on solids recovery for various feed rates. It can be seen that increasing the pool depth resulted in higher solids recovery. The exact opposite relationship was found for the cake solids concentration. It can also be seen that for a given pool depth increasing the feed rate resulted in a decreased suspended solids recovery and, while not shown, it was observed that this also resulted in an increase in cake solids concentration. Considering that one criteria for an acceptable dewatering process was a suspended solids recovery in excess of 95 percent, it was significant to note from Figure 2 that the maximum recovery obtained was 55 percent. The cake solids concentration associated with this recovery was approximately 35 percent. To increase the suspended solids recovery, a number of cationic polymers were investigated for

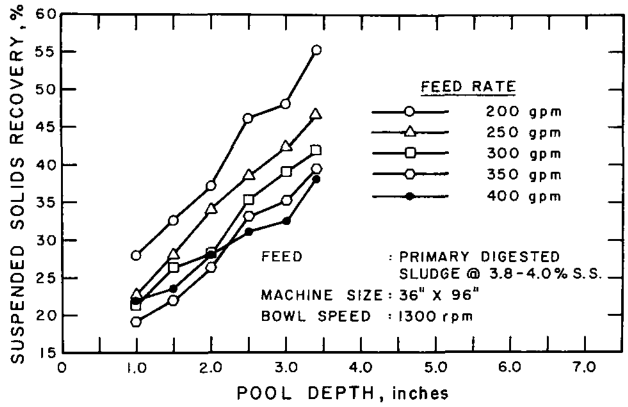

Figure 2: Relationship Between Suspended Solids Recovery and Pool Depth in a Horizontal Scroll Centrifuge.

use as conditioning agents. For the polymers investigated the centrifuge feed rate was maintained at 250 gpm, with the bowl speed held constant at 1300 rpm. For each polymer dosage the pool depth of the centrifuge was adjusted to obtain the maximum solids recovery. Shown in Figure 3 are the results of the evaluation for two typical polymers. While the performance of each polymer tested was slightly different from that of the others, it was generally concluded that to obtain a centrate containing a suspended solids centration of 1,500 mg/l or less (96 percent recovery), a polymer dosage of approximately ten lbs/ton was required. Corresponding cake solids ranged from 19 to 23 percent by weight. However, the performance of the centrifuge with polymer conditioning was erratic, At times it was not possible to duplicate the performance shown in Figure 3. This inconsistency in performance was thought to be the result of day-to-day variations in the characteristics of the digested sludge which interfered with and partially negated the activity of the polymer.

With regard to gravity thickened thermally-conditioned digested sludge, a six inch diameter pilot horizontal scroll centrifuge was used to evaluate its dewatering properties. It was determined that when the solids in the underflow from the thickener were dosed with approximately three lbs/ton of polymer and centrifuged, a solids recovery approximating 98 percent was achieved with corresponding cake solids of 25 percent. Blending this centrate with the supernatant from the thickener resulted in a combined suspended solids concentration of 3600 mg/l. Without polymer addition the recovery was 80 percent, while cake solids remained at 25 percent by weight.

Centrifugation: Imperforate Basket

An imperforate bowl basket centrifuge operates in a batch manner, using the same principles as a scroll centrifuge with the exception that cake removal is intermittent, not continuous. A basket centrifuge rotates around a vertical axis while scroll centrifuges generally operate in a horizontal position. Flow enters the machine at the bottom and is directed toward the outer wall of the basket. Cake continually builds up within the basket until the quality of the centrate, which overflows a weir at the top of the unit, begins to deteriorate. At that point, feed to the unit is stopped, the machine

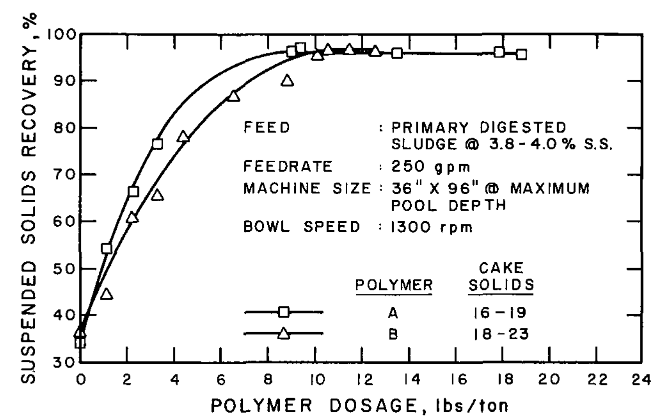

Figure 3: Horizontal Scroll Centrifuge Performance with Polymer Conditioning.

decelerates, and a nozzle-skimmer apparatus removes the liquid layer remaining in the unit. The skimmed contents are discharged through a hose. This is accomplished while the centrifuge is running at full speed. The skimmer is then retracted and the bowl is decelerated to a very slow speed whereupon the remaining dryer cake is peeled from the wall with a large bladed knife. The knifed contents fall through open quadrants at the bottom of the basket for conveyance to a discharge point. Upon retraction of the knife, the solids discharge cycle is completed. The bowl is reaccelerated to full speed and the feed cycle reinitiated. The buildup of solids in the bowl during the the feed cycle is such that those solids closest to the bowl wall contain the least amount of moisture, with the moisture content increasing towards the center of the basket.

The machine was evaluated as a second stage system to remove the solids remaining in the centrate from the existing horizontal scroll centrifuges. Initially a machine having a 30 inch diameter was examined. The unit was operated at a bowl speed to produce a G-force of 1300 at the outer wall of the bowl. With the feed rate varied from 15 to 50 gpm the maximum suspended solids recovery without sludge conditioning was approximately 80 percent. Using several of the cationic polymers that had produced satisfactory results in the horizontal scroll centrifuge evaluation, it was shown that the necessary suspended solids recovery of 95 percent could be achieved with a basket unit. However, to obtain more accurate data for full scale projections it was decided to continue the evaluation with a 40 inch diameter unit because this unit possessed most of the features of a full scale machine. Like the 30 inch unit the 40 inch machine had a G-force of 1300 at the bowl wall. In the operation of the unit the feed rate was varied from 20 to 60 gpm. This resulted in feed cycles ranging from 10 to 30 minutes. For all of the cycles approximately three minutes were needed to skim the liquid layer and knife the remaining cake solids in the bowl. With regard to the feed rate to the basket and its effect upon suspended solids recovery, the results can be seen in Figure 4. For the data shown the suspended solids feed concentration ranged from 2.5 to 3.0 percent, and to normalize this variation and that of the hydraulic feed rate, a mass feed rate in lb/hr was utilized. Figure 4 indicates that without sludge conditioning the suspended solids recovery was below 80 percent and decreased noticeably with an increasing feed rate. However, as can also be seen, with a cationic polymer dosage in the range of two to three lbs/ton it was possible to achieve a suspended solids recovery of approximately 96 percent, which resulted in a centrate suspended solids concentration of approximately 1500 mg/1. It is also of note that contrasted with the response achieved with no polymer addition, the suspended solids recovery of the polymer conditioned sludge was not noticeably affected by the range of feed rates. The effect of the mass feed rate on the composite cake solids concentration was shown in Figure 5. It can be seen that increasing the mass feed rate resulted in a decreased cake solids. However, for a given feed rate increasing the polymer dosage from one lb/ton to four lbs/ton resulted in an increased cake solids concentration. Polymer dosages in excess of four lbs/ton did little to increase the cake solids concentration. At a dosage of four lbs/ton cake solids of 20 to 22 percent were obtained, with a corresponding suspended solids recovery in excess of 95 percent, resulting in a centrate suspended solids concentration of approximately 1500 mg/1.

In summary, it was determined that a series system combining the existing horizontal scroll centrifuges as a first stage, and basket machines as the second stage, would produce a composite cake

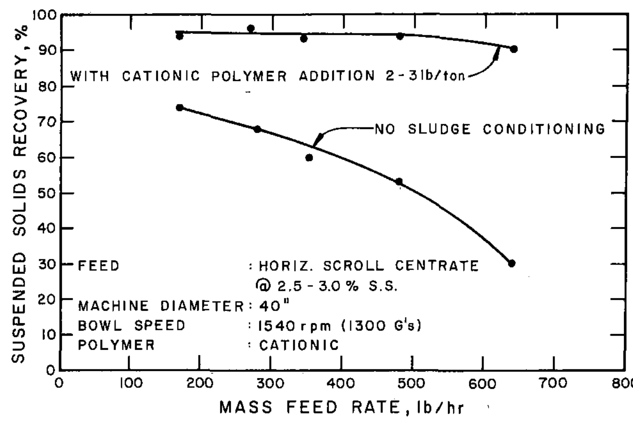

Figure 4: Effect of Polymer Conditioning on Solids Recovery in an Imperforate Bowl Basket Centrifuge.

of 25 percent solids by weight and a centrate suspended solids concentration of 1500 mg/1. This could be accomplished with a cationic polymer dosage of four lbs/ton to the basket centrifuges, and no sludge conditioning for the horizontal scroll units.

Pressure Filtration

The majority of the dewatering research conducted on the pressure filter used digested sludge as feed, because very early in the evaluation it was discovered that pressure filter dewatering of the centrate from the existing horizontal scroll centrifuges was not practicable. This was so because of the extremely wet cakes that were produced. It was felt that these wet cakes were mainly caused by the fine nature and low concentration of the suspended material in the centrate. Pressure filtration of digested sludge could not be accomplished without some form of conditioning. Therefore, the performance of the pressure filter was assessed on sludges conditioned by either chemicals (lime and ferric chloride), polymers, flyash or heat. All attempts to dewater polymer conditioned sludge proved to be totally unsuccessful due to rapid blinding of the filter media. Consequently, further evaluation of this type of conditioning was discontinued. An attempt was also made to thicken the digested sludge with polymers as a prelude to chemical conditioning in the hope that lower chemical requirements would result. However, such was not found to be the case.

The pilot unit was basically comprised of a sludge conditioning tank, two pressure tanks, an air compressor, a sludge transfer pump, and the pressure filter. The filter had a total filter area of 18 sq.ft., with the filter cloth being constructed of a monofilament polypropylene material. Wire mesh screens were used as a backing for the filter media.

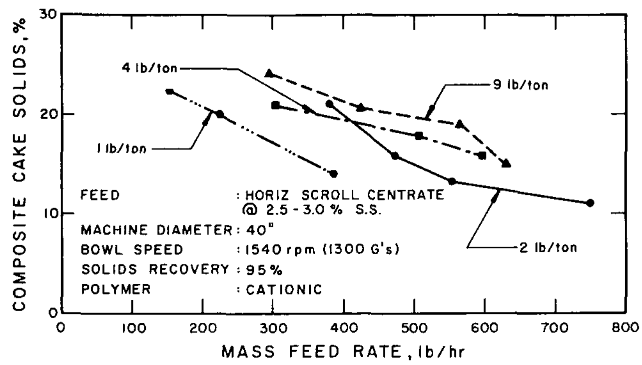

Figure 5: Effect of Polymer Conditioning on Cake Solids in an Imperforate Bowl Basket Centrifuge.

The operation of the unit was in a batch or cyclic mode and consisted of: (1) precoating of the filter surfaces, (2) sludge conditioning, (3) feed cycle (pressurization of the system), and (4) depressurization and cake discharge. The independent variables which control the operation of a pressure filter are the type of sludge conditioning, type of precoat, feed cycle time and feed pressure. All of these variables exert some influence on cake dryness and filtrate suspended solids. Precoat of the filter is necessary to prevent blinding and insure that the cake can discharge cleanly. Diatomaceous earth and flyash are two materials which are suitable for this purpose. In this work, the type and amount of precoat was kept constant for each form of sludge conditioning studied. When the sludge was conditioned by chemicals or heat, diatomaceous earth was used for the precoat; with ash conditioning, ash was used for the precoat. With sufficient conditioning the filtrate usually contained less than 100 mg/l of suspended solids. Consequently, filtrate quality was not a major concern in evaluating the pressure filter or in determining the operational criteria for its operation.

The majority of the pilot plant testing was done using lime and ferric chloride as conditioning agents. Various dosage combinations were investigated along with different feed cycles. Optimum results obtained by analysis of all the data indicated that a 40 percent cake could be produced with a two-hour feed cycle and chemical dosages of 500 lbs. of lime/ton, and 120 lbs. of ferric chloride/ton. However, because of the high chemical requirements, almost one-third of the solids in the cake was attributable to the conditioning agents. For these conditions the overall solids loading rate to the filter was 0.7 lbs/hr/ft^2.

Flyash conditioning was investigated as an alternative to chemical conditioning. The use of flyash is dependent upon incineration of the produced cake to obtain the ash conditioning material. Initially, studies were carried out using 2000 lbs/ton of flyash as a body feed material. Without the use of lime, a 37 percent cake was generated in a two-hour feed cycle; the solids loading rate, however, was low. When 450 lbs/ton of lime as $Ca(OH)_2$ was also added, generated cake dryness was increased to 47 percent solids by weight. This indicated the importance of lime addition for raising pH of the flyash conditioned sludge. Tests were run to determine the effects of increasing the ash dosage to 3000 to 4000 lbs/ton. For runs under similar conditions, conditioning with 4000 lbs/ton of flyash produced a dryer cake than with the lower ash dosage. At the higher ash dosage, an increase in the feed cycle time effected an increase in cake dryness. As noted, a small amount of lime was used to raise the pH of the conditioned sludge and induce coagulation. Following a one-hour feed cycle, a discharged cake of 43 percent solids by weight was generated. Increasing the feed cycle to three hours served only to increase cake dryness slightly. A corresponding reduction in solids loading was also effected. While the resulting cake was about 50 percent solids by weight, consideration was also given to the fact that two-thirds of the solids were recycled ash. Further analysis revealed that the ratio of water to sludge solids in that cake was the same as that optimally obtained with chemical conditioning.

With regards to heat conditioning, the dewatering characteristics of the pressure filter on both thickened and unthickened thermally-conditioned digested sludge were examined. The results indicated that thickening was required prior to filtration; however, no additional sludge conditioning was required, excepting the diatomaceous earth precoat for the filter. The optimum filter operation resulted in a filtrate suspended solids of less than 100 mg/1, a cake solids concentration of 38 percent, with a two-hour feed cycle. When the filtrate was combined with the supernatant from the gravity thickener the final effluent had a suspended solids concentration of less than 3,000 mg/l.

Vacuum Filtration

The pilot vacuum filtration studies encompassed an evaluation of a rotary drum coil filter and a rotary drum cloth belt filter. With either unit attempts to dewater the centrate from the existing horizontal scroll machines were completely unsuccessful. The failure was due to the large percentage of fine material in the centrate, which resulted in the lack of significant cake buildup on either the coil or cloth units. To alleviate the situation, polymers and chemicals were used to condition the centrate. However, the improvement in cake formation was slight and certainly not enough to merit further investigations. It was also not possible to dewater the primary digested sludge in any of the units without incorporating some form of conditioning. For both types of units the conditioning agents used were polymer, chemical (ferric chloride and/or lime), and thermal conditioning with and without intermediate thickening.

Coil Filter

The pilot plant evaluated at the JWPCP was equipped with a three-foot diameter drum having a one foot wide face. This provided a total filter area of approximately nine sq.ft. The filter employed stainless steel coil springs arranged in a corduroy fashion in two layers. Loading rate on the filter and the type and amount of conditioning agent were the major variables investigated.

For cationic polymer conditioning of digested sludge the results obtained with the coil filter can best be described as an all or nothing process. At polymer dosages below five lbs/ton solids recovery was sparsely achieved, and when achieved the generated cakes were thin and discharged poorly. Between five and nine lbs/ton the solids recovery generally increased with increasing dosage but was quite erratic. At polymer dosages of ten lbs/ton solids recovery stabilized between 90 and 98 percent; however, polymer dosages beyond this did nothing to enhance the situation. At polymer dosages of ten lbs/ton the solids recovery remained relatively unaffected by increased loading rates up to 18 lbs/hr/ft^2. Cake solids averaged approximately 18 percent by weight and remained within a constant range of 16 to 20 percent. With regard to chemical conditioning, combinations of ferric chloride and lime were used. The results indicated that a ferric chloride dosage of 80 lbs/ton and a lime dosage between 500 and 600 lbs/ton produced the optimum suspended solids recovery. At these conditions a solids recovery of 90 percent was achieved, with cake solids of approximately 26 percent by weight. Dewatering of thermally conditioned sludge on the coil filter was attempted. Cake formation, however, was negligible. When an intermediate thickening step was used, a dry (30 percent) filter cake was produced; the filtrate, however, contained a suspended solids concentration of 20,000 mg/1.

Of the three types of conditioning investigated, polymer conditioning was the only one that allowed effluent quality criteria to be met. Although this type of conditioning produced the wettest cake (18 percent),it also resulted in the highest solids recovery (95 percent).

Belt Filter

The pilot-scale belt filter was equipped with a three-foot diameter drum having a one-foot wide face. Filter leaf tests conducted with six different synthetic cloth materials enabled three to be selected for pilot testing. In the actual pilot plant work, best results were achieved with one belt material regardless of the type of conditioning. Only those results achieved with the one belt will be discussed. In addition to the types of filter material the other variables investigated were loading rate and type of conditioning. Laboratory tests revealed that cloth belt filtration of heat-conditioned digested sludge would not be possible without intermediate thickening. Similar tests also revealed that digested sludge would not filter directly unless preconditioned with at least ten lbs/ton of a cationic polymer or 400 lbs/ton of lime as $Ca(OH)_2$.

With regard to chemical conditioning, tests using lime as a conditioning agent were run at dosages from 400 to 800 lbs/ton. Acceptable filtrate quality occurred at loading rates up to 3.0 lbs/hr/ft^2; however, the cake produced at this loading was thin and did not readily discharge from the belt. Results of the pilot tests indicated that optimum conditions of filtrate quality and cake discharge were obtained at a lime dosage of 600 lbs/ton and a loading rate of 1.5 lbs/hr/ft^2, yielding filtrate suspended solids of 200 mg/1 and cake solids of 35 percent by weight. For polymer conditioning, a dosage of ten lbs/ton resulted in a filtrate suspended solids of approximately 500 mg/1 regardless of the solids loading rate. However, the resultant cake solids were in all cases wet and thin and lacked adequate discharge characteristics. Thermally conditioned, gravity thickened digested sludge was successfully dewatered with the belt filter. Using the underflow from the thickener a maximum loading rate of 3.3 lbs/hr/ft^2 was achieved, yielding a filtrate containing 1,300 mg/1 of suspended solids and a cake solids concentration of approximately 37 percent. No additional polymer or chemical conditioning was required to achieve this performance. Blending of the filtrate with the thickener overflow produced an effluent that contained approximately 3,200 mg/1 of suspended solids.

In general, it can be said that the belt filter was able to capture a majority of the suspended material from digested sludge conditioned thermally, chemically, or with polymers. Cake formation, however, differed markedly with each form of conditioning and had a significant effect on the loading rates required for producing a freely discharging cake.

Composite System Evaluation

Shown in Table 1 are the dewatering systems that met the effluent suspended solids criteria of 1500 mg/l or less. It should be noted that for the system comprised of thermal conditioning and gravity thickening, followed by belt vacuum filtration of the thickener underflow, it was felt that a separate biological treatment plant would be needed to reduce the high soluble BOD created during thermal conditioning. In addition, the effluent from the biological treatment plant would easily meet the suspended solids criteria. It should also be noted that for the other four systems the final effluent BOD was less than or equal to 1000 mg/l.

In selecting the systems shown in Table 1, consideration had to be given to the economic feasibility and to reliability of performance. Several combinations—in particular, pressure filtration of thickened thermally-conditioned sludge or horizontal scroll centrifugation of polymer conditioned, thickened thermally treated sludge—would likely meet the criteria if the resulting effluent were given additional treatment. However, such schemes were obviously uneconomical and hence were not considered further. With regard to performance reliability, polymer addition to the horizontal scroll centrifuges produced centrate that met the effluent criteria on occasion, but because of the nonreproducible results, this system was not considered a viable alternative. Performance of the basket centrifuge, the pressure filter, and the belt and coil vacuum filters was very reliable throughout the research project.

Economic Evaluation

Cost estimates were prepared for the systems listed in Table 1 to provide a rationale for selecting a full scale process. The estimates include capital and operating costs for the five selected dewatering systems and costs for ultimate disposal. In preparing the estimates the quantity of digested sludge solids used was 350 tons/day, with an additional 40 tons/day of solids being contributed from a future digester cleanings system. Thus a total solids quantity of 390 tons/day, having a suspended solids concentration of 3.8 percent was assumed as the influent for all systems. With regard to ultimate disposal incineration was not considered as a viable alternative because of the geographic limitations of the Los Angeles Basin, and thus disposal to a sanitary landfill had to be utilized. The paramount expenses involved in landfill disposal are vehicles to transport the sludge, loading facilities at the dewatering site, sludge storage and landfill disposal fees. The moisture

TABLE 1
Summary of Performance for Dewatering Systems

System	*Mode of Conditioning*	*Conditioning Dosage (lb/ton)*	*Effluent S.S. (mg/l)*	*Cake Solids (%)*	*Effluent[a] BOD (mg/l)*
Horizontal Scroll and Basket Centrifuge	Cationic Polymer to Basket	4	1,500	25	1,000
Pressure Filter	Ferric Chloride Lime	120 600	100	40	200
Coil Vacuum Filter	Cationic Polymer	10	1,500	20	1,000
Belt Vacuum Filter	Lime	600	800	35	500
Belt Vacuum Filter	Thermal and Gravity Thickening	--	3,000[b]	35	5,000[b]

[a] Estimated from a limited number of tests.
[b] Biological treatment of the effluent will reduce the BOD to 1,000 mg/l and the suspended solids to less than 500 mg l.

TABLE 2
Summary of Cost Estimates for Sludge Processing Systems

Item [a,b]	*Horizontal Scroll + Basket Centrifuges*	*Pressure Filter*	*Vacuum Filter - Polymer*	*Vacuum Filter - Chemical*	*Vacuum Filter Thermal + Thickening*
Dewatering System					
Capital - $	7,800,000	15,000,000	5,200,000	11,800,000	18,450,000
O & M -$	890,000	2,350,000	1,350,000	1,500,000	1,050,000
Annual Cost - $/ton	13.80	31.00	14.50	22.00	24.90
Hauling System					
Wet Tonnage - tons/day	1,560	1,300	1,950	1,500	860
Capital - $	5,000,000	4,400,000	6,400,000	4,900,000	3,150,000
O & M - $	1,800,000	1,550,000	2,300,000	1,750,000	1,100,000
Annual Cost - $/ton	22.60	20.30	28.90	22.00	14.00
Total System					
Capital - $	12,800,000	19,400,000	11,600,000	16,700,000	21,600,000
Annual Cost - $/yr.	5,180,000	7,300,000	6,190,000	6,270,000	5,550,000
Annual Cost - $/ton	36.40	51.30	43.40	44.00	38.90

[a]Quantity of sludge to be dewatered 390 tons/day. Disposal by truck hauling to a sanitary landfill located 30 miles from JWPCP.
[b]Capital Costs amortized at 6% for 10 years, excepting trucks and other vehicular equipment 6% for 3.4 years.

content of the dewatered sludge was considered a direct function of all these costs.

A summary of the capital, operation and maintenance, and yearly cost for all of the systems is shown in Table 2. To provide for an effective economic comparison between each system, common cost factors for hourly labor rates, power and fuel were used. All capital costs, excepting trucks and other necessary vehicular equipment, were amortized over a ten year period. This was deemed necessary because of the state of flux regarding standards on effluents discharged to the ocean, and thus it was felt that the dewatering system selected might only have a useful life of ten years. As indicated in Table 2, the unit costs of the dewatering systems ranged from less than $14/ton to $31/ton, with the lowest cost system being two stage centrifugation. One of the economic advantages of this system was the ability to utilize the existing horizontal scroll centrifuges. In this regard it should also be noted that the capital cost shown for the thermal conditioning—vacuum filtration system included a 2 mgd biological treatment plant. This was needed to provide acceptable limits for the suspended solids and BOD concentration of the system filtrate. With regard to the ultimate disposal systems, it can be seen that the annual costs ranged from $14/ton to approximately $29/ton, and that the costs varied directly with the total quantity of wet sludge to be hauled. The system producing the lowest amount of wet sludge was thermal conditioning and thickening followed by vacuum filtration. Thermal conditioning solubilizes a portion of the digested sludge solids and this fact, coupled with the relatively dry cake obtained when filtering the thickened conditioned sludge (35 percent solids), results in an appreciably lower quantity of sludge for disposal than the remaining systems.

When considering the combined costs for dewatering and ultimate disposal, the results as shown in Table 2 indicate that the two stage centrifugation system has the lowest overall cost. Based on the total system cost, this system was chosen as that to be implemented at the JWPCP. The economic advantage of this system was certainly influenced by the previously mentioned short life expectancy of the system and the present existence of the first stage horizontal scroll units. From the viewpoint of intangible benefits, the JWPCP treatment plant staff has over the years gained valuable knowledge regarding the operation and maintenance of centrifuges and the choice of the two stage system allows for the continued use of this knowledge. In addition, the utilization of the existing horizontal scroll centrifuges assured a continuation of the present use of the sludge as a soil conditioner. The other alternative dewatering systems would have produced sludges much finer in particle size distribution, and in the case of lime conditioning more alkaline, and these properties could certainly have presented problems in their use as effective soil conditioner.

SUMMARY

Pilot plant studies conducted at the JWPCP ascertained that five conditioning-dewatering systems were capable of meeting the established criteria of 95 percent solids recovery from an anaerobically digested sludge. Based on a solids quantity of 390 tons/day, an economic evaluation of each alternative was made the result of which was the selection of a two stage centrifugation system. The system utilized existing horizontal scroll centrifuges followed by imperforate bowl basket centrifuges. Cationic polymers at a dosage of 4 lb/ton were added to the influent of the second stage unit. The composite cake from both units will be hauled by truck to a sanitary landfill for ultimate disposal. The total system cost was estimated to be $36.40/ton.

PRESSURE FILTRATION—MUNICIPAL WASTEWATER SOLIDS, CEDAR RAPIDS, IOWA

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ABSTRACT

From pilot plant studies of numerous dewatering processes, Cedar Rapids selected the pressure filter and constructed the first major installation in the United States. Pilot dewatering studies indicated that fly ash was an effective filter aid reducing chemical conditioning costs from 20 to 4 dollars per ton dry solids. The full scale plant utilizes sludge cake incinerator ash as a conditioning agent.

A detailed nine month plant evaluation indicated the full scale plant exceeded performance of the pilot plant. Economic evaluations were made of operation and equipment. Some conclusions:

1. Pressure filtration of wastewater sludges is an effective and economical process.
2. Ash filter aid increases dewatering production and decrease chemical costs. Incinerated sewage sludge ash can be recycled as a filter aid. Power plant (coal) fly ash is most effective sludge conditioner.
3. A detailed pilot plant program is of great value in design of a full scale plant.
4. Some chemicals in combination with ash filter aid further improves dewatering efficiencies.
5. Technology and experience is extremely limited in the field of pressure filtration of wastewater solids.

INTRODUCTION

Cedar Rapids has used pilot plant studies to obtain design data for sludge dewatering facilities. Detailed pilot plant studies were conducted with several dewatering processes and the pressure filter system was selected as the most economical process. Test data compiled during the pilot scale pressure filter program was interpreted as a basis of design for a full scale pressure filter plant. This test data from the pilot plant at that time represented nearly all of the analytical data available on the operation of the pressure filter in the United States.

During the course of the dewatering studies it was observed that fly ash was an effective filter aid which cut chemical conditioning costs from about 20 to 4 dollars per ton dry solids. Economic evaluations of handling power plant fly ash were less favorable than those of on-site incinerated sludge ash and therefore multiple hearth sludge cake incineration with recycled sludge ash was constructed. Early information from Europe indicated that sludge ash due to its irregular and fine particle shape was a better sludge conditioner than fly ash. Field operation on both sludge ash and fly ash proved this to be incorrect.

For the application at Cedar Rapids, the pressure filter and the multiple hearth incinerator was the most economical combination of dewatering incineration processes. Evaluating capital investment and fuel operating costs, this combination was estimated to be 10.3 percent less cost per ton of dry sewage solids dewatered and incinerated over the vacuum filter-incinerator combination. Other dewatering systems considered were even less favorable in cost comparison. Some other factors favoring the pressure filter selection are: less building space, less operator attendance, closed system with fewer odor problems, drier cake, greater solids capture, clear filtrate, lower power requirements, expandable capacity of filter unit.

The full scale pressure filter sludge dewatering facility was designed on the basis of experiences with the pilot scale pressure filter and with the expectations that the performance of the pressure filter could be improved. It was planned to have the pressure filter and accessories as completely automated as was practical and to monitor and control most functions from a central console.

Summary of Design Data

Digester Solids

Total Solids	56,000 lbs/day
Volatile Solids	26,400 lbs/day
Percent Solids in Sludge	5.5
Solids Source	Primary and 2-Stage Trickling Filters

Pressure Filter

Two units each 83 plates, 64 inch, 207 cu. ft.
3400 sq. ft., expandable to 100 plates.

Pressure Filter Loadings

Ash/Sludge Ratio	1.5:1	1:1
Filtration Time per Cycle Hr.	1.5	1.0
Total Cycle Time-Hours	2.0	1.25
Total Filtration Time Hr/Day	16	16.7
Cake Moisture-Percent	52	60
Yield Filter Cake-Lbs/Sq.Ft./Hour	0.75	0.65
Filtrate Suspended Solids	Nil	Nil
Chemical Required	None	None

Other Plant Data

Population:		
	Present	113,000
	20 Year Future	172,000
	BOD Equivalent	810,000
Plant Flow:		
	Average, MGD	28.6
	Wet Weather, MGD	64.4
Construction Sludge Dewatering Completed:		1972

General Description of the Pressure Filter Process

Solids are periodically pumped from the secondary digesters to the solids holding tanks. Bottom solids from the sludge holding tanks are removed by pump on a demand basis and sent through preconditioning facilities to the pressure filters where the sludge is dewatered.

The sludge preconditioning facilities consist of sludge grinders, mix tanks where ash and/or chemicals are added as a filter aid, contact tanks where slow mix of filter aids and flocculation occur, and variable rate sludge pumps to feed the filter.

The pressure filters consist of a series of plates covered with nylon, or similar, filter cloth. Sludge is pumped through the filter leaving a solids deposition on the filter cloth. This solids formation, or filter cake, is periodically discharged at the end of the filter cycle. The filter cycle may be one to two hours depending upon numerous variables.

Cake discharged from pressure filter is broken and then fed to the multiple hearth furnace for incineration. Filtrate removed from the solids in the pressure filter is discharged back through the plant for further treatment.

Details of a typical pressure filter plate are shown in a cross-section view in Figure 1. Conditioned sludge is pumped to the filter by variable speed, variable capacity, variable pressure pumps, automatically controlled to decrease the output capacity as the pumping head increases until it reaches a maximum stall pressure of approximately 225 psi. Prior to beginning of the filter cycle, the pressure filter is precoated to protect the filter cloth from blinding or clogging due to possible grease content or fine particles, and to form a shear plane between the cloth and cake to assure free and clean discharge of the cake. Filter precoat is a mixture of ash carried to the filter cloth with recycled filtrate water. Immediately after precoat, the sludge feed to the pressure filter is automatically applied through motorized control valves to begin the filtration cycle. The duration of the filtration cycle may be determined by time, pressure, or rate of filtrate flow. Usual operation will be controlled by rate of filtrate wherein the filtration continues until a predetermined rate of filtrate flow is observed across the V-notch weir. At the end of the filtration cycle the filter core feeding the individual filter plates remains filled with wet, soft sludge slurry. This soft core is blown out using air prior to opening the filter to discharge the cake. The filter cake is discharged to the bunker below the pressure filter and is sheared into smaller particles as it passes shear cables stretched across the opening below the filter. From the cake bunker it is conveyed to the multiple hearth incinerator and the incinerated ash is recycled to process. The process schematic and photographs are shown in Figure 2.

Study Results

Digested sludge at Cedar Rapids is unusually difficult to dewater. It became apparent early in the operation of the full scale plant that to assure reasonable operation on a continuous basis, a

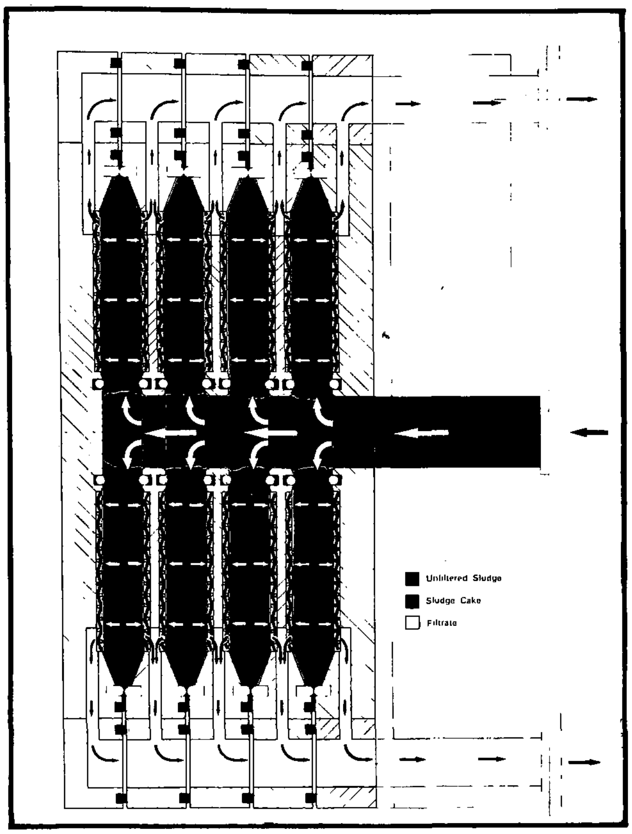

Figure 1: Cross Section View and Flow Diagram of Plate Section.

sludge conditioning monitor was necessary. During the pilot plant operation sludge feed was conditioned on a batch basis with admixtures carefully predetermined. Filterability of a sludge can be defined as the ease at which the sludge gives up water. It is desirable to be capable of objectively describing a numerical value to a sludge to give us a meaningful value for operation. Specific resistance has proved valuable at Cedar Rapids as a sludge conditioning monitor in a day-to-day operation. By using the specific resistance, an operator can:

1. Determine whether a sludge is conditioned properly.
2. Evaluate and optimize new methods of conditioning such as organic polymers.
3. Evaluate the filterability of the unconditioned sludge.

The resistance meter is essentially a pressurized Buchner funnel and is simple to operate by the attending personnel. Specific resistance becomes meaningful when it becomes known what value a sludge must have to filter well. Unconditioned sludge may have a value greater than 366 ($366 \times 10^{12} cm^{-2}$). Generally speaking, at Cedar Rapids a conditioned sludge must have a specific resistance of less than ten to filter well. Knowing this limit, we can optimize sludge conditioning (ash and chemicals) using the resistance meter or bench filter much more easily and rapidly than by a trial and error method on the full scale filter.

Filter Performance

The design data for the pressure filter was originally developed using fly ash for sludge conditioning. The full scale plant used sludge ash recycled from the incinerator. Soon after the plant was on line it became apparent there was a lack of correlation between the pilot plant study and the performance of the full scale filter, and that the full scale plant could not successfully operate at any reasonable sludge/ash ratio without using ferric chloride and lime. Consequently a program and study was set up comparing the two different ashes. Figure 3 indicates the comparative filterability between sludge/ash and fly ash conditioning. This data indicates that fly ash is 2.5 to 3.0 times more effective for conditioning digested sludge per unit weight of fly ash than sludge ash. Additional comparisons have been made using fly ash and sludge ash for conditioning other sludges including raw primary sludge, straight domestic sludges, other complex industrial wastes-domestic sludges. In all cases it has been seen that fly ash was consistently better than sludge ash. Studies by others have found a difference between sludge ash and fly ash, but in reverse order, therefore it appears that the fly ash and possibly the sludge ash in Cedar Rapids are unique, and results cannot be directly applied to other cities. Fly ash and sludge ash can differ in three fundamental ways: chemically, by size and by shape. Chemically, fly ash and sludge ash are quite dissimilar. Fly ash is approximately 50 percent silica and sludge ash is approximately 50 percent calcium oxide. Other components, such as ferric oxide and alumina are present in different quantities. The effect of these higher levels of iron and aluminum salts in fly ash is not known, and further research is required. Fly ash has a smaller particle size than does sludge ash. Ash fractions of smaller size $<45\mu$, are significantly far more effective for sludge conditioning than ash of larger size, $<45\mu$.

Concern has been expressed that in sludge filtration processes using recycled incinerated sludge ash as a filter aid, the recycling of ash through the incinerator may result in a shift of ash particles to the smaller particle sizes. This concern is based on the premise that the fine fraction of ash is not effective in sludge conditioning and may in effect be deleterious. Ash samples were collected and stored and later extensive tests using the same

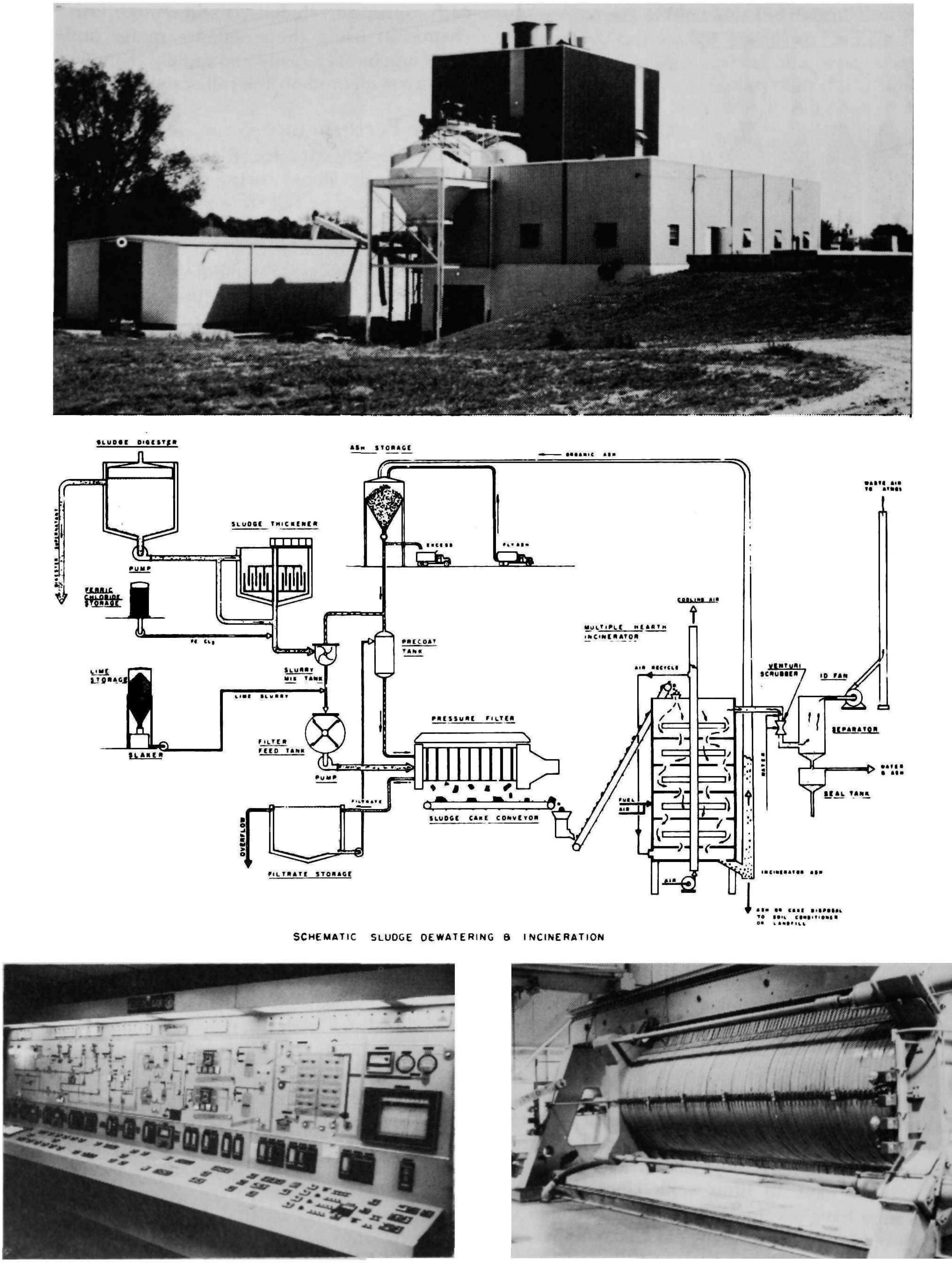

Figure 2: Proposed Layout.

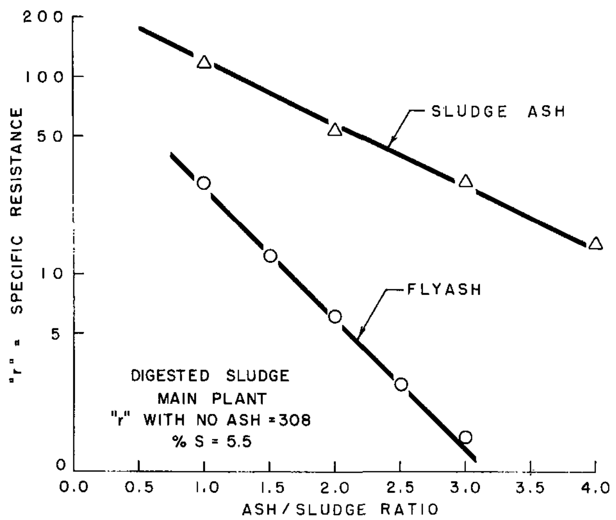

Figure 3.

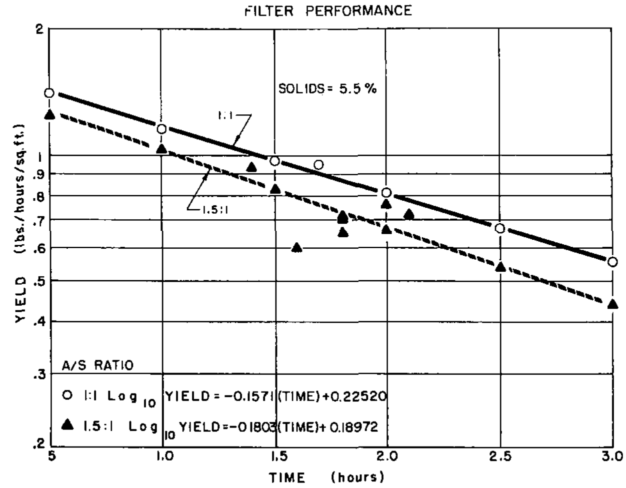

Figure 4: Filter Performance.

digested sludge, indicated that a decreasing ash particle size enhances the ability of the ash to condition the sludge. Samples conditioned with fractions of ash below 32μ had less filter resistance than the original mixture and the most effective fraction of ash was that fraction below 15μ. It appears that the recycle of ash, with the subsequent increases in the fraction of fines when recycled through an incinerator, is not a problem.

Early in the operation of the pressure filter, it also became apparent that the digested sludge could not be conditioned satisfactorily with sludge ash alone. After extensive testing, ferric chloride and lime dosages were determined which are still basically in use today. Filter performance curves were established following the filtration rate (yield) in terms of pounds per hour per square foot, vs. time in hours at various sludge solids concentrations. A typical curve for 5.5 percent solids is shown in Figure 4. Performance indicates that filter yield increases in almost direct proportion to increased raw sludge solids density at a ratio of about 1.8/1, that is, if the sludge density is increased times 2, the resulting filter yield is increased times 1.8.

It is apparent that properly conditioned sludge filters satisfactorily at both low and high sludge densities, and that yield is principally influenced by time to completely fill the cavity forming the predetermined cake volume. In practice it became apparent that the limiting factor to improving yield was the ability to pump conditioned solids to the pressure filter in sufficient capacity to develop the maximum rate of filtration. Sludge cake is discharged from the pressure filter and is about 58 inches in diameter, 1½ inches thick, weighs approximately 200 pounds. Each pressure filter produces 83 cakes per cycle, and at normal operation cake moisture content is in the range of 36-38 percent and the appearance is dense, dry and textured. The specific weight of the discharge filter cake varies from 107 to 114 pounds per cubic foot dependent upon the moisture content and the ash ratio. Cake discharged from the filter to the cake storage bunker is sheared by a series of cables which tends to bulk the broken cake. Bulked filter cake was determined to be approximately 47 pounds per cubic foot, but this was for cake not exposed to the impact and compressive forces due to dropping. Cake discharged from the bottom of the hopper under compressed conditions of superimposed loads of ten to twelve feet depth had a specific weight of 83 pounds per cubic foot.

Conditioned sludge applied to the pressure filter forms a cake structure which almost immediately serves as the principal filter media. The filter cloth has served only as the base structure for this development, and after the cake has formed to 1/16 or 1/8 inch thickness, the influence of the filter cloth is negligible for continued filter performance. As the cake continues to form, the filter void is filled, the total resistance increases rapidly developing full pressure differential in possibly 30-40 minutes. Continued full pressure differential of about 225 psi is desirable to assure most of the free water has the time to travel through the cake and underdrainage system to be disposed of as filtrate. The noteworthy point after the development of the full cake formation is that prolonged high pressure does very little to further dewater the cake.

For a seven month period the filtrate averaged 74 mg/l suspended solids while the sludge solids.

averaged 4.60 percent solids giving a removal of suspended solids of 99.99984 percent. The BOD and COD of the filtrate are due primarily to dissolved organics such as volatile acids and are not necessarily affected by the filtering process.

Dewatering Raw Primary Sludge

In-plant arrangements were made to dewater raw primary sludge on a test basis. The filterability of raw sludge is generally much better than digested sludge at Cedar Rapids. Better performance was maintained at lower ash/sludge ratios with a 1:1 ash/sludge ratio valid for all solids concentrations. Pressure filter cake averaged 54-56-58 percent solids for filter feed solids of 5-6-8 percent respectively. Volatile solids content was much higher providing good incinerator feed and no difficulty was experienced in conveying the raw sludge filter cake. Filtrate suspended solids showed no basic difference from digested sludge, averaging 79 mg/1; however, a significant increase occurred in BOD and COD values. The mean value of filter runs are:

Digested: COD mg/1 510; BOD_5 mg/l 300; BOD_5/COD (%) 56
Raw: COD mg/l 7080; BOD_5 mg/l 5700; BOD_5/COD (%) 81

Process Evaluation

Labor and chemical costs were based on actual costs in 1972, including labor benefits. Hourly rates were about $4.50 ± for different classifications of operators. Management and laboratory costs are not included. The dewatering facilities were bid in December 1968, and all construction costs have been interpreted to 1972 increased costs. All costs were evaluated to filtration capacity regardless of the operating capacities experienced at any given time during the study.

The total cost for pressure filtration is composed of four separate costs. These costs are labor for maintenance and operation, power, chemicals for conditioning, and capital investment, see Table 1.

Labor costs were determined, as described before, to be $3.82 per hour filtration. Power costs were determined in the same manner to be $0.80 per hour filtration. Likewise capital costs were determined to be $9.55 per hour filtration. In the compilation of the data, each cost was determined as:

$$\text{Cost/Ton} \quad \frac{\text{cycle time (hours) x cost factor}}{\text{tons dry solids/filter}}$$

Cycle time represents the time to complete a filter run. Added to filtration time, approximately 0.4 hour is required to discharge the cake, refill the filter with filtrate, and precoat, and is referred to as turn-around time.

Cycle time (hours) = filtration time (hours) ÷ 0.4 hours turn-around

The cost factor represents the dollar per hour value placed upon each cost.

Chemical costs were determined for each cycle by measurement of actual quantities of lime and ferric chloride used to condition the sludge.

Figure 5 shows cost data for 5.5 percent feed solids. Costs for other solids concentration varied as follows:

% Total Solids Feed	4.5%	5.5%	6.5%
Operating $/Ton	5.83	4.69	3.83
Capital	12.05	9.71	7.91
Total(including chemical)	26.83	21.69	18.20

Having operated the pressure filter pilot plant at an early date when no analytical data was available for evaluation and guidance, and having developed the design criteria for a full scale plant from pilot studies, Cedar Rapids has observed the process performance without bias to other installation performances. The full scale plant process is highly automated and therefore reflected some of the malfunctions associated with equipment failure from numerous interrelated units. Some unsatisfactory process performance was experienced during the early days of start-up and check-out. Much of this was related to inadequate training of the operating personnel, particularly those of the equipment manufacturer. It is understandable that the first major installation would offer some degree of challenge on the start-up and that experience would make the next one easier. A general evaluation of the pressure filter process confirms the performance predicted by the pilot plant study, and that the process offers distinct advantages over other forms of sludge dewatering based upon Cedar Rapids' sludge. Performance can be maintained over a wide range of feed sludge concentrations, with particular note in the low solids level ranging to 2.5 percent.

Proper precoat is essential to satisfactory filter performance and precoat pressure is an important control for assuring good cake formation. Normal precoat pressure for clean filter media starts at about 25 psig and ranges upward to 40 psig. Above this operating range it appears that gradual deterioration of filter performance often occurs. To

TABLE 1
Costs for Pressure Filtration

	Man-Hours/Hour Filtration		*$/Hour*	*Filtration*
Operation Foreman	0.90		$4.13	
Assistant	0.33	1.23	1.37	$5.50
Maintenance Foreman	0.17		0.76	
Assistant	0.33	0.50	1.37	2.13
		1.73		$7.63

Labor costs per filter (÷ 2 units) — $3.82/hour filtration
Power costs 40 KWH/hour filtration x $0.02 — 0.80/hour filtration
Chemical Costs: Ferric Chloride $130/ton — 0.065/pound
Lime 22/ton — 0.0114/pound
Capital Costs: 20 years at 4¼%, 5½days/week - 286 working days/yr.
Building $ 417,000
Equipment 1,255,000
$1,672,000 = $19.10/hour ÷ 2 units
$ 9.55/hour filtration

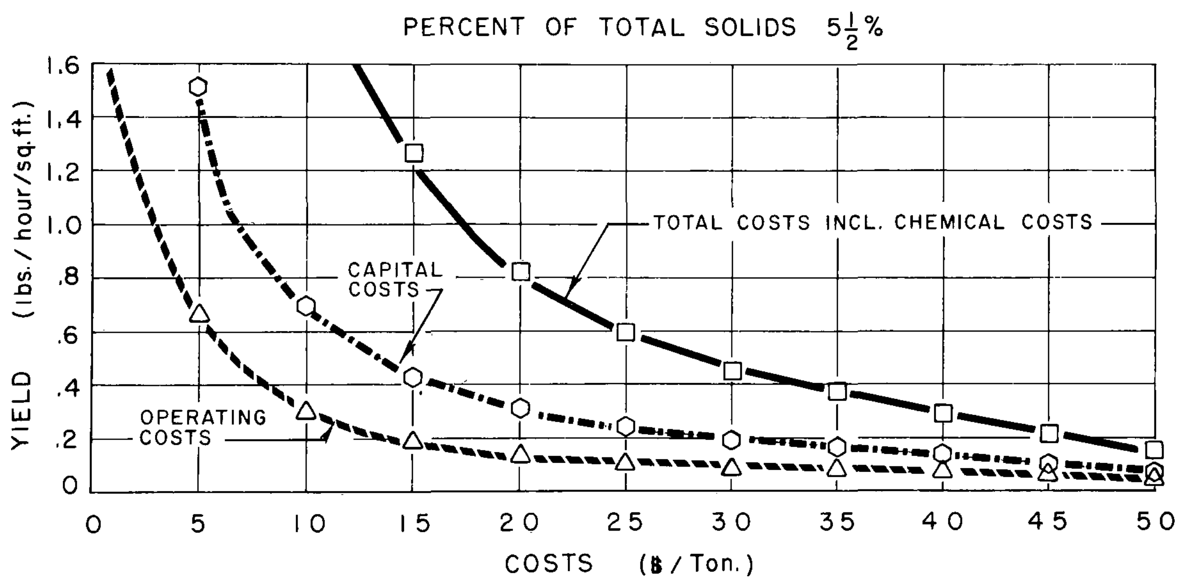

Figure 5.

operate within the precoat pressure range it is necessary to have properly conditioned raw sludge applied to the filter and to have had the proper quantity of ash precoat. Improperly conditioned raw feed sludge will cause some buildup on the media and thus gradually raise the successive precoat pressures. Often this problem can be corrected by dropping the quantity of precoat from 150 to 50 pounds, thus forming a new cleavage plane encouraging the discharge cake to remove some accumulated precoat. Improper quantities of precoat may cause a gradual buildup whereby the excess ash creates a shear plane distant from the filter medias so that when the cake breaks away excess precoat remains on the media. Operating experience which had reduced the precoat pressure, or at least prolonged the need for a complete filter wash is that of extending filter fill cycles. During the fill cycle, filtrate water is pumped into the filter and by continuing recirculation of the overflow it is sometimes possible to perform some degree of washing. This practice is not totally successful but it may reduce the precoat pressure by 10 psig which may extend the need for a complete filter wash for a few days.

Estimated filter runs between media washes is about 100 runs, or 150 to 200 filter hours of operation. The method of washing a pressure filter could stand much improvement. The wash rod originally furnished with a series of high pressure nozzles is no longer used. A more successful system has been a single high pressure nozzle with a broad discharge operating at about 750 pounds pressure. Commercial grade detergent is used in the washing solution.

Cake and incinerated ash grinders were originally installed because the German process recommendations stressed this requirement. Experience at Cedar Rapids confirmed that cake grinding was undesirable and that incinerated ash grinding was unnecessary. Cake passing through the grinder tended to knead to a plastic-like ball and under high moisture content of about 55 percent into the grinder, came out more as an extrudable paste.

Ash feeders used at Cedar Rapids are of the gravimetric type. These were installed for accurate proportioning of ash. Feeder problems are associated with both the unpredictable fluidizing and compaction characteristics of ash in storage. It is difficult to cover both extreme properties of ash, and experience would suggest the most simple feeder, such as a volumetric feeder to be more trouble-free.

Cake handling facilities were the cause of many problems, primarily because no experience had existed in discharging filter cake to bunker storage. The bulk density of broken filter cake in the bunker was greatly underestimated at about 48 pounds per cubic foot which is reasonable under normal conditions. However, dropping 200 pound cakes into bunker storage recompacted the mass to about 83 pounds per cubic foot at the drag conveyor discharge.

Filter feed pumps are hydraulic driven ram pumps having a variable capacity, variable head characteristic. Pumps having these characteristics are desirable as the filter cycle pressure develops and the input diminishes, however, a more suitable primary pump should be provided to meet the early demands of the filter, particularly on a filter installation as large as Cedar Rapids. Considerable experimentation was carried out by the plant operating personnel wherein filter performance was greatly improved by placing all four filter feed pumps on one filter rather than the normal two units. Prolonged slow feed rates to the pressure filter to form satisfactory cake development is uncertain from our observations with sewage sludges and ash precoat. Where a precoat system is not used, it may be desirable and even necessary to slowly develop a cake on the cloth to provide a protective zone so that the solids are not driven into the cloth upon increasing pressure. With a precoat system the protective zone is already established and through-put should be as rapid as possible.

Pressure filter plate warpage has been the major problem from Day One. Some of this has been attributed to the early day of operation when the plates were inadequately shimmed, however, adequate shimming of the stay bosses has not totally eliminated this problem. Warpage occurring in the plate diaphragm transfers bending to the plate frame which in turn accelerates plate gasket deterioration due to warped gasket seating plane. To date, over 100 plates have been, or will be, replaced due to material fatigue and failure. Most failures have occurred as ruptures of the diaphragm either around the stay bosses, or at the top or bottom at the rim. It is apparent that once structural change has occurred, no practical means of compensating for that change has been developed for this design and the only solution is to replace the bent or distorted plates without further experimentation. There are two basic causes for plate warpage, either improper shimming or the application of dissimilar cloth to a given plate. Inadequate precoat may eventually lead to a pressure differential across a plate, however, this should be obvious before damage may occur and corrective remedies taken.

Many of the numerous problems and failures have been attributed to poor shop workmanship and field service. Many modifications have been made and after three years, they continue to be made. Equipment and process improve with experience of people in specific applications, therefore, it is reasonable to assume that the pressure filter for sewage sludge dewatering will be improved in both design and operation.

SUMMARY

Looking back to the expectations of the pilot plant study, and to the process performance observed in the full scale plant, it is obvious that the pressure filter process is dependable, economical, and offers distinct advantages over other forms of sludge dewatering based upon Cedar Rapids' sludge. The process has achieved a higher quality product with greater capacity in the full scale plant than was predicted by the pilot plant study. Cake quality is maintained over a broad range of sludge solids concentrations, particularly at the low solids level (2.5 - 4.5 percent) which were not previously experienced in the pilot studies. It is also obvious that with the limited pressure filtration experience available, it would be ill-advised to design an application without extensive pilot study, which study should include a prototype pressure filter in addition to the minimal bench scale studies. The product of pressure filtration is an increase in solids concentration in the cake with a decrease in suspended solids content in the filtrate. Compared to other systems for sludge dewatering, the advantages for pressure filtration may be summarized as follows:

1. The quantities of sludge conditioners are usually reduced.
2. Filtration efficiency is maintained over a broad range of sludge characteristics.
3. Increased solids content of the filter cake.
4. Extremely low filtrate suspended solids and BOD.
5. Minimal operation and manpower requirements.
6. Minimal maintenance of equipment.
7. More convenient cake disposal due to lower moisture and smaller volumes.
8. Total costs, capital plus operation, are competitive.

HEAT TREATMENT AND INCINERATION

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With increased regulatory agencies' requirements for higher quality treatment of municipal wastes, biological treatment, particularly some form of the activated sludge process, has become the most common method of treatment in most areas of the country. As a result, municipal wastewater treatment plants are faced with disposal of a greatly increased volume of primary and waste biological solids.

Sludge Disposal Alternates

As illustrated in Figure 1, the alternates are digestion and dewatering versus heat treatment and dewatering versus dewatering and combustion. With digestion, there is approximately 80 cubic feet per million gallons of dewatered sludge for final disposal—without digestion, 130 cubic feet per million gallons. With heat treatment, there is approximately 65 cubic feet per million gallons of sludge for final disposal. The lesser amount of sludge after heat treatment is due to a drier cake than when dewatering the digested sludge. The dewatering and combustion requires disposal of only four cubic feet per million gallons and this is an inert ash.

Heat treatment has been practiced in this country for the past several years. Basically, heat treatment is nothing more than heating waste sludges to approximately 400°F, and maintaining it at this temperature for approximately 30 minutes. The result of heat treatment will be a sludge with greatly improved dewaterability characteristics. The improved dewaterability of the sludge will result in drier cakes discharged from the dewatering device.

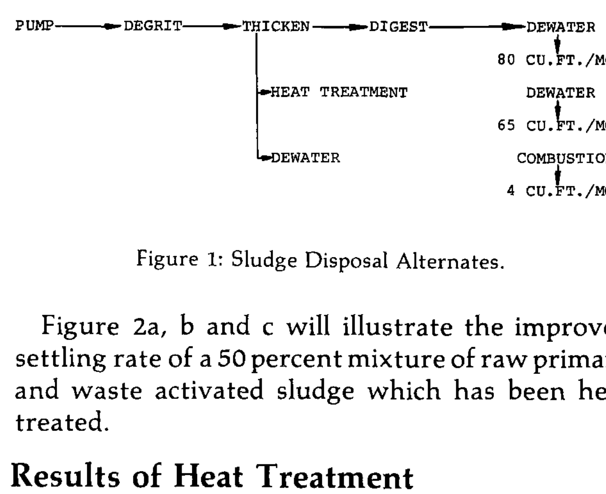

Figure 1: Sludge Disposal Alternates.

Figure 2a, b and c will illustrate the improved settling rate of a 50 percent mixture of raw primary and waste activated sludge which has been heat treated.

Results of Heat Treatment

Table 1 illustrates the comparison between dewatering heat treated sludge and chemically conditioned sludge. The sludges for these tests were approximately 50 percent primary and 50 percent activated. Test runs with heat treatment marked "C" produced cakes of 39 percent plus total solids while the capture was 95 percent plus without any chemicals.

Dewatering the same sludge but without heat treatment, indicated as "NC", produced cakes of only 18.9 percent total solids. Capture in the centrifuge was only about 52 percent without polymers on the raw sludge. In order to achieve the captures of 95 percent plus when dewatering the raw sludges, chemical costs of approximately $13 per ton of dry solids were required. Solids capacities of the centrifuge with heat treated sludges were double those when dewatering raw sludges.

Table 2 summarizes the effects of heat treatment at a full-scale plant (6000 gph). The sludge at the

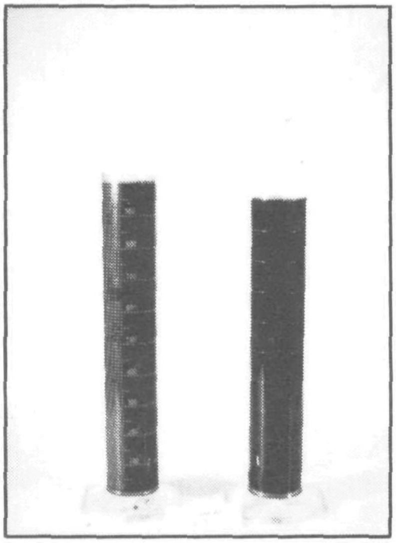

Figure 2a: 0 Minutes.

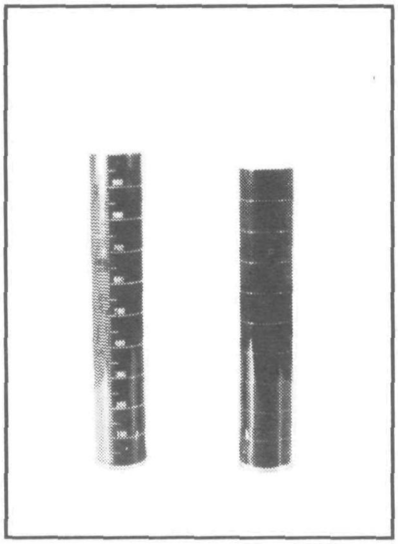

Figure 2b: 2 Minutes.

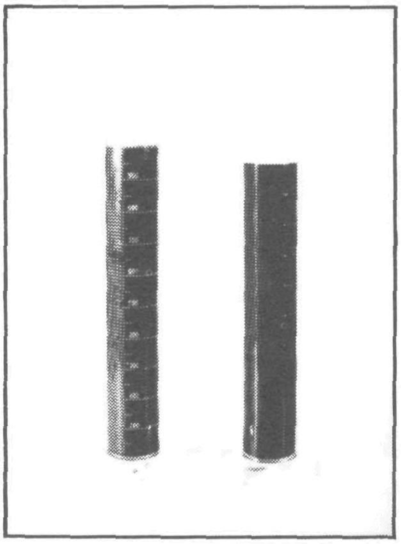

Figure 2c: 5 Minutes.

TABLE 1
Swindon Pilot Plant Tests
Centrifuge Tests
RP + AS

Test No.	*Product*		*Recovery*	*Chemical Cost*
	lb/hr. DS	*% TS*	*%*	*$/Ton*
72C	77	41.6	98.4	0.00
75C	117	41.3	95.2	0.00
54C	160	39.6	97.9	0.00
63NC	34	18.9	51.9	0.00
65NC	72	18.9	96.6	12.95

Swindon, England
Heat Treatment Conditions: Temperature = 400° F
Reaction Time = 30 Minutes

time of the test was a mixture of approximately 60 percent primary and 40 percent waste activated sludge. Note the effect of decreasing heat treatment temperature on the decreasing centrifuged cake concentration.

Recovery in the centrate was lower than expected and simultaneously cake concentration was higher. To compensate for this situation the pool depth in the centrifuge will be increased by changing the regulating rings to a smaller inner diameter. With this change, cake concentrations of 40 percent will be obtainable with centrate recoveries in the range of 90-95 percent when heat treatment temperatures are approximately 385°F. Product rates of 800 lbs/hr. D.S. could be obtained consistently from each centrifuge when the dewatered cake concentration was at least 40 percent.

Advantages of Heat Treatment

This experience using mechanical dewatering devices on heat treated mixtures of primary plus waste activated sludge has indicated the following advantages over dewatering the corresponding raw chemically conditioned sludge:

A. Double the cake solids concentration in the dewatering unit is possible.
B. Double the cake solids capacity of the dewater device is possible.
C. Significant reduction or elimination of chemical conditioning agents, depending on the ratio of primary to secondary solids being heat treated, and on the type of dewatering unti being used, can be achieved.
D. When combined with combustion, a smaller incinerator can be utilized due to lower water content in the feed cake.
E. No fuel will normally be required for incineration. When the ratio of volatile matter to water in the dewatered heat treated sludge cake is approximately 0.4, the dewatered cake is autogenous.

Heat treatment of sewage sludges does produce liquors high in soluble BOD. This is due to the so-called hydrolyzation that takes place and also to the leaching of the cell water from the structure during heat treatment. In those plants in which primary plus waste activated sludges are heat treated, the recycled heat treatment liquor contains a dissolved BOD load approximately equal to 25 percent of the primary settled sewage.

Like the supernatant from a digester, handling the sludge heat treatment liquors is part of the

TABLE 2
San Bernardino Farrer Plant
Operating Results

Centrifuge Operation (w/o Chemical Cond.)

Temperature °F	*Reaction Time (Minutes)*	*Feed Conc. (%TS)*	*Cake Conc. (%TS)*	*Prod. Rate. (#/Hr.D.S.)*	*Recovery %*
385	30	10.3	55.5	485	90
385	30	12.4	53.2	547	89
385	30	14.9	51.9	833	83
365	30	13.0	35.5	804	82
360	30	9.7	33.3	690	83

solids handling system which is true of all return streams from the solids handling system, such as thickener overflow, centrate or filtrate.

•Of course, if the cost of handling the liquors from heat treatment is such that it offsets the overall economics of heat treatment in the first place, then there would be little reason to even consider the process. However, our data indicates that the BOD in the liquors is biodegradable and can be handled without offsetting the overall economics of the heat treatment plant.

Dorr-Oliver's practice is that in those sewage treatment plants where the wet end aeration tanks are sized for six hours detention time, the heat treatment liquors can be returned directly to the head of the sewage treatment plant. In those cases where the aeration detention time would be less than the nominal six hours, the Dorr-Oliver Sludge Heat Treatment System would incorporate a pretreatment of the heat treatment liquor before returning this liquor to the head end of the sewage treatment plant.

Incineration

Incineration of primary and biological solids has been practiced in the United States for many years. The fluid-bed incinerator and the multiple hearth incinerator are the most common units utilized in the municipal market.

Dorr-Oliver has supplied a total of 94 fluid-bed reactor systems for handling biological sludges. Of the 94, a total of 74 are for incineration of municipal sludges. The remaining 20 installations are incinerating biological sludges produced at industrial waste treatment plants.

Of the 74 municipal installations, five installations include heat treatment, two of which are in operation.

Table 3 shows performance data from eleven FluoSolids* installations. The plants shown do not incorporate heat treatment prior to incineration. Two of the installations are at primary treatment plants, four at plants burning sludges produced at trickling filter plants, and five are burning sludges produced at activated sludge plants.

The average design capacity of the eleven installations is 764 lbs/hr. dry solids. The actual average operating capacity is 851, which is 11.4 percent higher than the design capacity. Average design auxiliary fuel requirement is 57.6 gal/ton dry solids. The actual average fuel oil consumption is 48.2 gal/ton dry solids.

The average design power requirement is 280 kwh/ton dry solids. The actual power consumption is 248 kwh/ton dry solids.

The volatile content in the ash was 0.49 percent, as compared to a design content of 3.1 percent.

The stack emission was 0.0318 grains/scf, as compared to a design of 0.12 grains/scf.

The average cost of incineration is $30.44 per ton of dry solids for power, fuel oil, and polymers required to chemically condition the sludge.

This figure is based on a fuel oil cost of 30¢/gal, a power cost of 1.2¢/kwh and a polymer cost of $1/lb.

Heat treatment and dewatering of municipal sludges will produce a sterile and relatively dry cake which can be disposed of in a land or ocean disposal operation.

Combustion of municipal sludges will produce an inert ash, greatly reducing the volume of solids to be disposed of.

The combustion of heat treatment and fluid bed incineration offers the opportunity to greatly reduce the volume of municipal sludge to an inert ash at improved operating cost.

The cost evaluation of a combined heat treatment-fluid bed incinerator installation versus

* FLUOSOLIDS and FS are registered trademarks of Dorr-Oliver Incorporated.

TABLE 3
FS Performance Data

Plant	Type of Sludge	FS Reactor Dia.	Heat Re-Covery	Capacity #/Hr. D.S.		Aux. Fuel Gal/Ton D.S.		Power KWH/Ton D.S.		% Volatile In Ash		Stack Emissions Grains/SCF	
				Design	Actual	Design	Actual	Design	Actual	Design	Actual	Design	Actual
Liberty, N.Y.	Prim + T.F.	6′	No	282	338	102.8	53.3	-	-	3.0	0.31	-	-
Ocean City, Md.	Prim	6′	No	350	445	48.0	22.9	-	-'	3.0	0.85	-	-
Barstow, Cal.	Prim	7′	No	500	552	36.0	31.9	239	210	-	-	0.1	0.025
Northwest Bergen, N.J.	Prim + WAS	12′	Yes	1100	1169	41.5	57.0	267	243	4.0	0.59	0.1	0.018
Upper Merion Twp., Penna.	Prim + T.F.	9′	Yes	865	918	18.4	14.4	-	-	-	-	-	-
Port Wash., N.Y.	Prim + T.F.	9′-6″	No	860	865	64.5	85.5	252	261	3.0	0.4	0.1	0.025
Arlington, N.Y.	Prim + WAS	9′	No	700	742	-	-	-	-	3.0	0.3	-	-
New Windsor, N.Y.	Prim ' T.F.	7′	No	570	666	56.6	75.5	-	-	3.0	0.4	-	-
Bath, N.Y.	Prim + WAS	9′-6″	No	605	657	113.9	85.5	400	344	3.0	0.4	0.1	0.044
Lorain, Ohio	Prim + WAS	14′	No	1400	1635	40.0	32.2	274	181	3.0	0.7	-	-
Somerset-Raritan	Prim + WAS	12′	Yes	1170	1376	55.0	23.8	247	247	3.0	0.5	0.2	0.047
Average				764	851	57.6	48.2	280	248	3.1	0.49	0.12	0.0318

a fluid bed incinerator utilizing polymers to chemically condition the sludges is shown.

The heat treatment-fluid bed system utilizes heat recovery from the reactor to produce steam required in the heat treatment process.

The fluid bed system with chemical conditioning utilizes heat recovery to preheat the fluidizing air to 1000°F.

The combination of heat treatment and incineration offers the opportunity to improve the economics of sludge disposal by greatly improving the dewaterability of the sludge and by significantly reducing or eliminating chemical conditioning agents utilized in sludge dewatering and auxiliary fuel required to sustain combustion in the incinerator.

APPENDIX A
Dorr-Oliver Solids Handling System Cost Evaluation

Design Basis

Plant Flow at 20 MGD

Solids at 34,285 Lbs/D; 2,000 Lbs/Hr. (120 Hrs./Wk.)

Alternate No. 1 Heat Treatment, Centrifuge Dewatering, FS Combustion with Heat Recovery.

Alternate No. 2 Chemical Conditioning, Centrifuge Dewatering, FS Combustion with Heat Recovery.

Basic Equipment

	Alternate No. 1	*Alternate No. 2*
Heat Conditioning	6000 GPH	—
Centrifuges	4 - 16-L's	6 16-L's
FS Reactor	1 13′ ∅	1 17′ ∅

Operating Requirements & Costs

	Alternate No. 1	*Alternate No. 2*
Boiler Feed Water		
Lbs./Hr. Na_2SO_3	0.19	0
Lbs./Hr. NaCl	3.73	0
Cost/Ton D.S. $	0.71	0
Power		
KWH/Hr.	250	240
Cost/Ton D.S. $	3.00	2.88
Fuel		
Gallons/Hr.	0	43.2
Cost/Ton D.S. $	0	12.96
Polymers		
Lbs./Hr.	0	15
Cost/Ton D.S. $	0	20.25
Potable Water		
Gallons/Hr.	960	0
Cost/Ton D.S. $	0.14	0
Start-Up Fuel		
Gallons/Hr.	3.83	0.42
Cost/Ton D.S. $	1.15	0.13
Labor		
Men/Hr.	2	2
Cost/Ton D.S. $	9.00	9.00
Maintenance		
Cost/Ton D.S. $	7.66	7.80
Cost of Heat Conditioning Liquors		
Cost/Ton D.S. - $ (140 HP)	1.25	0
Total Operating Cost		
Cost/Ton D.S. $	22.27	53.02
Capital Costs (Erected System)	1,771,000	1,234,000
Capital Costs (Civil Works to House & Support System)	708,400	493,600
Total Capital Costs	2,479,400	1,727,000
Amortized Costs/ Ton D.S.	20.66	14.40
Total Operating Cost/Ton D.S.	22.27	53.02
Total Cost/Ton D.S.	42.93	67.42

Operating Cost Basis

Power	= $0.012 KWN
Fuel	= $0.30/Gallon
Polymers	= $1.35/Lb.
Na_2SO_3	= $0.07/Lb.
NaCl	= $0.0155/Lb.
Potable Water	= $0.015/1000 Gallons
Labor	= $4.50/Hr.

DRYING OF SLUDGE FOR MARKETING AS FERTILIZER

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Houston, Texas

Evaluation of the drying of sludge for marketing as fertilizer usually is made after less complicated processes such as sand bed drying, lagooning, or the spreading of liquid sludge on land are found not to be feasible; and that mechanical processing will be required. The comparison then is between drying with the sale of the dried material as fertilizer and incineration with land disposal of the ash. These are not just choices in the final sludge process, but must be evaluated for various water reclamation processes on a system basis.

Incineration may be applied to any type of sludge following mechanical dewatering by centrifugal, floatation, or filtration processes. However, in order to produce a marketable fertilizer it is necessary to keep the nitrogen content as high as possible, and minimize the moisture, ash, grease, and cellulose. This normally means drying activated sludge, as anaerobic digestion increases the ash content, and primary sedimentation tank sludge is high in grease, fiber, and even carbohydrates. There are a number of local dryer installations that dry digested sludge for sale as an excellent soil conditioner. Heat dried activated sludge has been produced for nearly fifty years in Chicago, Milwaukee, and Houston and sold in all parts of the United States, Canada, and Mexico. In the market, it must compete with other sources of organic nitrogen such as dried blood, fish scraps, tankage, and cottonseed meal.

Although the material may be priced on the basis of its nitrogen and phosphorus content, the cost to the buyer includes the cost of freight on the total weight of the material. The cost of the freight on the inert material ultimately affects the price that the producer receives for the sale of the material. Thus the effect of low nitrogen on the price can be more than linear, and can cause the material to be unmarketable when transportation is involved. Therefore, it is well to consider the things that affect the nitrogen content of sludge.

The principal components of activated sludge are microbial cells, grease, cellulose fiber, and inorganic insoluble materials. The analytical procedures usually used—nitrogen, ash, ether soluble material, and crude fiber—do not accurately follow this classification. Microbial cells contain both inorganic and ether soluble material. Disregarding this minor discrepancy, the cells may be estimated to be equal to the volatile matter minus the crude fiber and ether soluble material. It has been found at Houston that when the cells are evaluated on this basis they contain about ten percent nitrogen. The nitrogen content of the dried sludge depends upon the degree of dilution of the cell content by ash, grease, fiber, and moisture. This is illustrated in Figure 1 which shows how ash affects the nitrogen content. The phosphorus content is not predictable in a similar manner because it may be part of the cells or incorporated as an inorganic precipitate. Ash content increases during wet weather and decreases during dry periods. Food processing wastes with low ash content tend to increase the cells without increasing the ash, and thus, increase the nitrogen content.

The processes used at Houston are shown in Figure 2. The water reclamation processes are designed to be compatible with the sludge disposal scheme of drying and marketing as fertilizer.

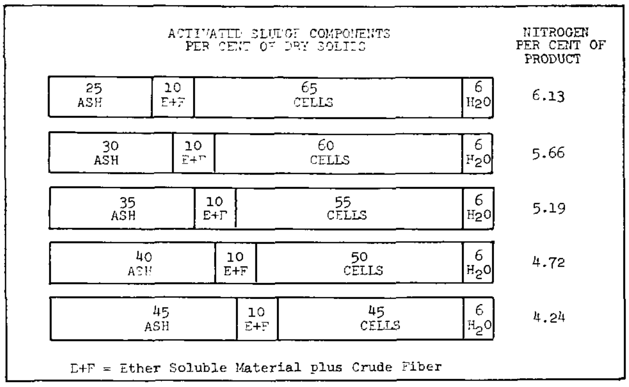

Figure 1: Variation of Nitrogen in Product as Cells Are Diluted with Other Components.

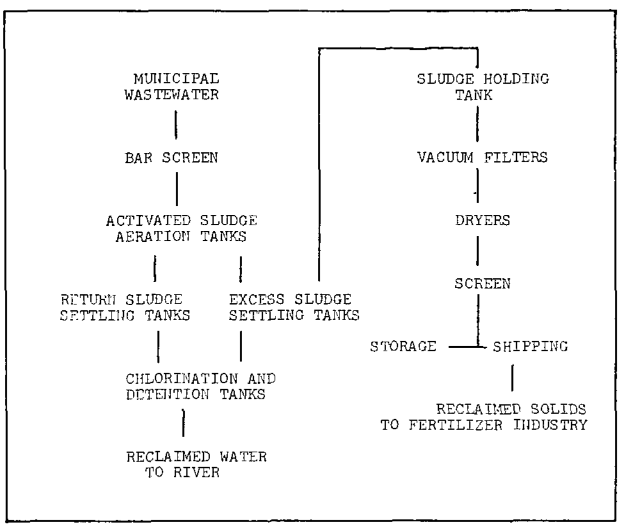

Figure 2: Water and Solids Reclamation Processes at Houston, Texas.

Bar screens were installed to minimize problems in the activated sludge process. In the early 50's, screenings were ground and returned to the flow. The shredded rags were found to reagglomerate into large wads of waste. The grinder was removed and screenings hauled to a sanitary landfill. A philosophy evolved, "If you take it out, keep it out." This same philosophy was then applied to the organic return pumps on the grit washers. The removal of stringy material is beneficial to filter operation, since strings accumulate on the agitator and on the scraper blade. This has been particularly noticeable when bar screens have been taken out of service for repair and sewage bypassed around them.

The grit removal facilities remove large particles and thus offer some protection to the pumps, but they have little affect on the ash content of the sludge. Where air distribution is maintained in the aeration tanks there is no deposition of sand.

The original activated sludge plants at North Side and South Side did not have primary settling tanks. As drying was added to the operations, it became part of the system to omit them. This minimizes the exposure of raw sewage and eliminates one unit operation.

The activated sludge tanks have been sized to provide eight hours detention based on the raw sewage flow in dry weather. The final settling tanks provide for an overflow rate of 1800 gpd/ft.^{2} at peak flow.

Excess sludge is taken from a thickener fed mixed liquor. The overflow, which is normally of good quality, goes to the plant effluent. In the enlargement under construction at the North Side plant, new thickeners are included with recycle of the overflow to the aeration tanks (consideration has been given to the need to be able to sample influent sewage prior to the addition of return flows from the sludge processing operation.) The thickeners are designed for a solids loading of 10 lb/day/ft^2. The operation of the thickeners is critical to the sludge filter operation and requires regular manual attention. If there is no appreciable return of solids from the sludge drying plant, then the mixed liquor flow to the thickeners gives a measure of the growth rate of the sludge in the activated sludge plant.

When all flows from the drying plant are recycled, stand-by drying capacity becomes important. Control of the activated sludge process is lost when solids cannot be dried as fast as they are produced. As solids accumulate in the aeration tanks, the sludge age increases and the filterability often decreases. The ability to catch-up from high loads or plant shut-downs is necessary. When operation is 24 hours/day, 365 days per year, a 25 percent spare capacity would permit catch-up in eight days following a two day shut down. When operation is based on less than 21 shifts per week, then the unused shifts are available for catch-up.

The holding tank is sized for one hour detention time to provide for brief interruption of sludge pumping without interruption of the dryers, and to provide sufficient sludge for orderly shut-down in event of total pump failure.

Sludge conditioning is a key step in the filter operation. Ferric chloride has been the coagulant at Houston. The dose required is about ten percent of the dry solids. This produces a pH of about 2.9 in the sludge and pH 3.8 at the cake discharge. The iron content of the sludge is only slightly increased and ferrous iron and other divalent cations are released into the filtrate. Lime has not been helpful except in large doses to give a pH of 10. This is not desirable as fertilizer manufacturers often blend ammoniacal compounds with the sludge, and the high pH would cause the release of ammonia. Moreover, the nitrogen would be diluted by not only the calcium carbonate, but also, the ferrous iron which would be retained as ferrous hydroxide.

The vacuum filters are 12 feet diameter by 16 feet face, having 600 square feet of filter surface. The filterability of the sludge has varied about four-fold in the past decade—in 1964, the yield was 3 lb/hr/sf and it has been as low as 0.75 lb/hr/sf in the last two years. Coincidental with this change in filter yield has been an indicated decrease in fiber from 7.5 percent to 0. There was also a corresponding increase in nitrogen. Laboratory studies at Houston have indicated that bacteria metabolizing cellulose fiber grow at 23 percent per day at laboratory temperature of 72°F. This corresponds to a sludge age of 4.3 days. The source of fiber is paper in the sewage, but the likelihood of restoring the fiber content by stopping its degradation is very low. Effluent BOD requirements of 12 or 10 mg/l which are indicated for the near future will require a sludge age of five to eight days which is more than adequate for biological degradation of the fiber. Therefore, new drying plants are being designed on the basis of current experience.

The sludge dryers are C-E Raymond Flash Dryers (Figure 3) with 14 feet diameter cyclones and heat exchangers for high temperature deodorization. They have a rated evaporative capacity of 12,000 lb. water per hour while producing a product with five percent moisture. They are normally operated at a loading of 8,000 to 10,000 lb. of water per hour. Deodorization temperature is controlled at around 1100°F and the stack temperature is about 500°F. The fuel used is natural gas and the heat input is about 22 million BTU per hour.

Dried sludge is conveyed in screw conveyors to minimize the dust emission. The vapors from sludge conditioned with ferric chloride are acidic and corrosive, so stainless steel troughs are used. Hard iron bearings have been found to be successful. The material is weighed and then screened on six by six mesh screens. The oversize material is mostly trash and is hauled to a sanitary landfill. The screened material is stored until shipped. For shipment the material is fed to an elevator, weighed in automatic batch scales, and allowed to flow by gravity into a boxcar. A "car trimmer", a high speed conveyor about 15 feet long, is used in the car to throw the material to the end of the car.

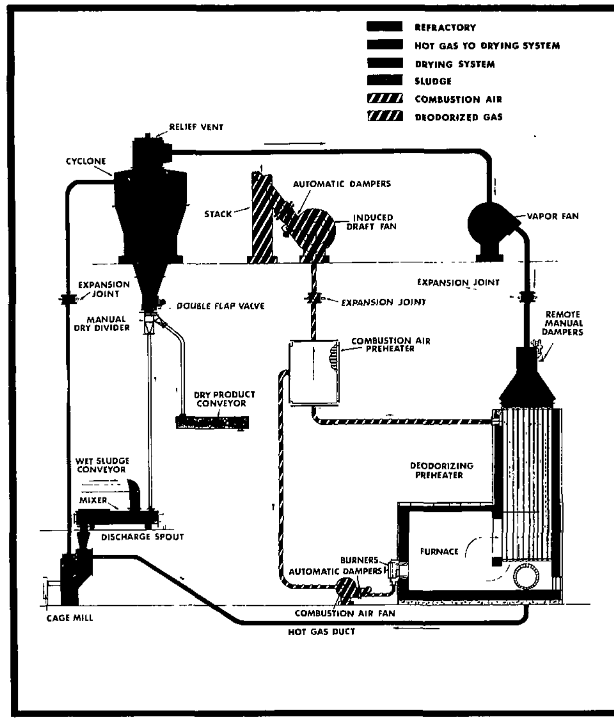

Figure 3: The C-E Raymond Flash Drying System for Sludge Drying Only . . with Deodorization.

The Houston dried activated sludge is sold under the copyrighted trade mark of Hou-Actinite. The marketing has been through a contract with a brokerage firm. The contract which is for a five year period is awarded on the basis of competitive bidding. The material is sold to fertilizer manufacturers who usually blend it with other materials to produce a balanced fertilizer. The revenue to the City of Houston is approximately $21 per ton. The material is priced on the basis of analyses by the City laboratory using official methods of the Association of Official Agricultural Chemists (AOAC). The market is greatest in the winter and spring, and least in summer. It has been necessary at times to store as much as 20 percent of the annual production before the market picks up in the fall.

Through the use of the activated sludge process and the drying and marketing of the solids removed, Houston and other cities are treating sewage to a sparkling effluent and recycling the solids to beneficial use in an aesthetically acceptable form.

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GROWTH OF BARLEY IRRIGATED WITH WASTEWATER SLUDGE CONTAINING PHOSPHATE PRECIPITANTS

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ABSTRACT

Barley (*Hordeum vulgare* L., var. Bearded), grown for 16 weeks in pots of loam soil, was irrigated for seven weeks with wet sludges containing precipitated phosphates to see if chemically-treated sludges could be used agriculturally. Raw primary sludge and primary sludges from alum and ferric chloride addition to raw wastewater, each either limed or unlimed, were added at two different rates, corresponding to a total application of 23 or 46 m tons/ha/yr. The elemental composition of the plants and the total and extractable phosphorus in the soil were determined. The results showed that barley plants irrigated with the three types of sludges grew as well as those supplied with inorganic fertilizer. Fertilized plants, however, yielded more grain than sludge-treated plants. Slight variations in nutrient content of the sludge-treated plants appear to be due to differences in the concentration and availability of the elements in the soil. Differences in total soil phosphorus among the treatments were not significant. The limed and unlimed alum-treated soils and the unlimed iron-treated soil had significantly more extractable phosphorus. Liming significantly decreased extractable phosphorus only in the iron-treated soil. Ninety-two percent of the phosphorus added by the sludges was still in the sludge crust at the end of the experiment. The results demonstrated that the presence of phosphate precipitated by Al or Fe did not limit growth, and that sludges containing phosphate precipitants can be used, at least on a short-term basis, to grow barley.

Phosphorus in the form of phosphate is one of the major uncontrolled pollutants in wastewater[3]. It is a primary nutrient for algal growth in surface waters. Removal of phosphate in sewage is now required by law in several states, particularly those with plants discharging effluents into waters that drain into the Great Lakes. Phosphorus is precipitated by the polyvalent cations in aluminum salts, iron salts, or lime, which can be added at various points during wastewater treatment. Removal of phosphorus by aluminum or iron salts is especially desirable because extensive modification of the sewage treatment process is not needed. In the most frequently used procedure, the salt is mixed with the wastewater just before the primary clarifier. Many smaller plants in the United States and Canada are using this method[8].

Aluminum or iron salts are added to wastewater in an atomic ratio of 1.5 to 2.5 metal atoms per P atom. The mechanism of P removal is obscure, but it is pictured as being effected by the formation of the metal phosphate and the metal hydroxide. Adsorption may take place, and/or the phosphate may be included in a complex metal hydroxide ligand[6].

If plants are grown on land spread with the sludge, the phosphate precipitated into sludge during wastewater treatment may be in a form unavailable for plant growth. In fact, the excess metal hydroxide may react with the natural soil phosphate and make it less available. Jansson (Uppsala, Sweden) reported on P availability in soils spread with chemically treated sludges. His results, in what appears to be the only published study on the subject[10], indicate that iron and alum sludges with excess hydroxides did not bind exchangeable phosphate in the soil, and P availability was not decreased. Under field conditions and with adequately-limed soils, application of alum and iron sludges resulted in a slow but positive phosphate reaction. On acid, lime-poor soils, the effect was unfavorable. But such soils, Jansson pointed out, are not consistent with rational land use and they should be limed. In greenhouse studies, he found that corn grew just as well on a loam soil fertilized with superphosphate as on the same soil treated with alum sludges.

Before wastewater sludge is applied to land, it is most commonly stabilized by digestion or chemical treatment[5,7], which can reduce odors and the pathogen level[1,4,12]. Digestion decreases the biodegradability potential of the sludge. This is desirable because localized high temperatures or anaerobic conditions caused by rapid breakdown of the sludge are less likely to occur and cause adverse growing conditions. Chemical treatment of sludge with lime is effective in minimizing odors and probably is better than digestion in reducing the number of pathogens. The ultimate biodegradability potential of sludge is not reduced by lime, but it does slow the degradation rate.

The object of this investigation was to determine the availability of P in Al-primary and Fe-primary sludges stabilized with lime before their disposal on land. To accomplish this aim, the growth of barley in pots of soil with and without inorganic fertilizer was compared with the growth of barley on soil amended with the following four types of sludges: 1) lime-treated primary sludge with no Al or Fe salts; 2) lime-treated primary sludge containing Al or Fe salts; 3) primary sludge with Al or Fe salts, but with no lime; 4) primary sludge with no Al or Fe salts and no lime.

Materials and Methods

Three sludges were obtained from the Lebanon, Ohio (30 miles from Cincinnati, Ohio) sewage treatment plant: a raw sludge from conventional primary treatment (referred to as primary sludge); a raw sludge from primary treatment of wastewater with 93 mg/l of alum ($Al_2(SO_4)_3 \bullet 14H_2O$) added as a phosphorus precipitant (referred to as Al-primary sludge); and a raw sludge from primary treatment with 48 mg/l $FeCl_3$ as a precipitant (referred to as Fe-primary sludge). In both chemical treatment cases, the atomic ratio of added metal to total P in the raw wastewater was 2/1.

After being transported to Cincinnati from Lebanon, the sludge sat overnight in a refrigerator (5°C) to allow the solids and supernatant to separate. The precipitate was adjusted to two percent solids on a dry-weight basis with the use of the supernatant. This two percent sludge was analyzed for pH, total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN), ammonia nitrogen (NH_3), chemical oxygen demand (COD), and for the elements Fe, Mn, Zn, Na, B, Al, P, N, K, Ca, and Mg.

Procedures described in *Standard Methods*[14] were used to analyze for pH, TS, VS, TKN, NH_3, and COD.

Ca, Mg, Na, and K analyses were performed in the following manner. A 1.00-g sample of dry sludge was heated with 20 to 30 ml of 1:4 HCl (20 percent HCl solution) on a hot plate. After boiling for a few minutes, the sample was cooled and filtered into a one-liter volumetric flask. The residue was washed, and the filtrate was diluted to one liter. The sample was then analyzed following standard procedures for wastewater analysis[14].

Al, Cd, Cu, Fe, Mn, Ni, Pb, Zn, and P analyses were conducted as follows. A 1.00-g sample of the dried sludge was heated with 10 ml of 1:1 H_2SO_4 + 10 ml concentrated HNO_3 until the first appearance of dense white fumes. After cooling, 2 ml of a 3:1 (vol/vol) HNO_3 + $HClO_4$ acid mixture was added. Digestion was continued until the first appearance of dense white fumes. The sample was cooled and 30 to 40 ml of water was added. After filtering through a Gooch glass filter crucible into a one-liter flask and diluting to volume, it was analyzed on a Perkin-Elmer 303 Atomic Absorption Spectrophotometer for the metals and on a Technicon Autoanalyzer for P. The sludge crust was analyzed for P by the same procedure.

The experiment, which lasted 110 days (9 July to 26 October, 1973) consisted of eight kinds of treatments, each at two levels, replicated three times for a total of 48 pots. The treatments were as follows:

1. soil (unfertilized)—water
2. soil (fertilized)—water
3. soil—unlimed sludge (no Al or Fe)
4. soil—limed sludge (no Al or Fe)
5. soil—unlimed Al sludge
6. soil—limed Al sludge
7. soil—unlimed Fe sludge
8. soil—limed Fe sludge

Water and sludge (two percent solids) were added at two levels: 235 ml/wk and 470 ml/wk. Each application was equivalent to a depth of 1.25 cm and 2.5 cm of liquid sludges; or 2.5 m tons/ha (1.11 tons/A) and 5.0 m tons/ha (2.23 tons/A) of dry sludge solids. For the limed sludges, a ten percent

CaO slurry was added until a pH of 11.8 was reached.

Fifteen barley seeds (*Hordeum vulgare* L., var. Bearded) were planted in each of the 48 plastic pots (23 cm tall; 18 cm diameter) on 9 July 1973 (Day 1). The pH of the loam soil ranged from 7.4 to 8.1, and the cation exchange capacity was 20 meq per 100 g. The appropriate sludge (with or without lime, Al, or Fe) was added two times, on 25 May and on 29 May 1973, to the soil surface before the seeds were planted. Chemical fertilizer was mixed into the soil of the six fertilized pots before the seeds were planted, to supply 227-99-187 kg per ha of N-P-K, respectively. The plants were thinned to ten plants per pot on 16 July.

Distilled water was added ten times to the pots (a total of 3,045 ml/pot) between the time that the sludge was added to the soil (29 May) and the time the first sludge applications were made after planting (3 August). Leaching did not occur until the last day of distilled water additions (27 July) before sludge applications, and then only a small amount of leachate collected in the pans under the pots. Between 3 August and 14 September, 235 ml or 470 ml of sludge was poured weekly on the soil surface (seven additions). The control pots (fertilized and unfertilized) received 235 ml or 470 ml of distilled water. Four days after each sludge or distilled water addition, 235 ml of distilled water was added to every pot. From 14 September to 26 October, 235 ml of distilled water was added twice a week to each pot (11 additions). Table 1 shows the days on which sludge and water were added to the pots. There were nine applications altogether of sludge, amounting to 22.5 m ton/hectare (10 ton/acre) of dry sludge solids for the low level of addition, and 45 m ton/hectare (20 ton/acre) for the high level.

The plants were grown in a greenhouse in Cincinnati, Ohio, under natural light conditions. After the plants were thinned (16 July), there were approximately 24 cloudy days and 77 sunny days until the end of the experiment. A cooler in the greenhouse kept the temperature below about 32°C. Temperature varied from 11°C to 32°C and the humidity from 40 percent to 98 percent. Plant height, pot weight, and par evaporation rate were recorded weekly.

On 26 October, the plants were harvested by cutting them 1 cm above the sludge or soil surface, separating them into stems, leaves, and grain, and measuring fresh weight. The plant samples were oven dried at 80°C, weighed, and ground in a Wiley mill. Samples were digested in concentrated H_2SO_4 with a Cu catalyst[16] and analyzed for total N (micro-Kjeldahl steam distillation technique), P

TABLE 1
Timing and Amount of Sludge or Distilled Water Additions to Pots Containing a Loam Soil in which Barley Plants Grew

Date	*Day*	*Sludge added*	*Distilled water added to control pots (no sludge, but with or without fertilizer)*	*Distilled water added to all pots*
			ml	
25 May	45	235 or 470		
29 May	41	235 or 470		
5 June	34			460
25 June	14			235
2 July	7			235
9 July	1	(planting)		235
13 July	5			235
16 July	8			235
20 July	12			470
24 July	16			235
25 July	17			235
27 July	19			470
3 Aug	26	235 or 470	235 or 470	
8 Aug	31			235
10 Aug	33	235 or 470	235 or 470	
14 Aug	37			235
17 Aug	40	235 or 470	235 or 470	
21 Aug	44			235
24 Aug	47	235 or 470	235 or 470	
28 Aug	51			235
31 Aug	54	235 or 470	235 or 470	
4 Sept	58			235
7 Sept	61	235 or 470	235 or 470	
11 Sept	65			235
14 Sept	68	235 or 470	235 or 470	
18 Sept	72			235
21 Sept	75			235
25 Sept	79			235
28 Sept	82			235
2 Oct	86			235
5 Oct	89			235
9 Oct	93			235
12 Oct	96			235
16 Oct	100			235
19 Oct	103			235
23 Oct	107			235
26 Oct	110	(harvest)		

(Autoanalyzer), K, Mg, Ca (flame photometer) and trace elements (Atomic Absorption Spectrophotometer).

At the end of the experiment, a glass tube (1 cm diameter) was used to take two soil samples—one from the top half and one from the bottom half of the soil in each pot. The soil was analyzed for total P with the use of Na_2CO_3 fusion technique[9] and for extractable P with the use of the Bray No. 1 test[13] which employs a 0.03 $\underline{N}$ NH_4F in 0.025 $\underline{N}$ HCl extracting solution at soil to solution ratio of 1:10.

TABLE 2
Characteristics of Sludge from the Lebanon, Ohio Sewage Treatment Plant (Average of Four Samples)

Characteristic	*Primary sludge*	*Al-primary sludge*	*Fe-primary sludge*
	Sludge before adjustment to 2% solids		
Total Solids, %	7.6	2.9	2.8
Volatile solids, %	64.2	66.5	68.3
	Sludge after adjustment to 2% solids		
Total solids, %	2.1	2.0	2.1
pH	5.7	6.4	6.6
	mg/l		
COD	29,500	27,800	26,900
Total nitrogen	695	680	680
Ammonia nitrogen	92	103	110
	mg/g		
Ca	26.1	37.9	30.0
Mg	3.2	3.9	3.3
K	0.8	1.0	0.8
Na	1.0	2.5	4.1
P	9.1	26.7	27.7
Al	5.9	18.1	6.8
B	$<$0.1	0.6	$<$0.1
Cd	$<$0.1	$<$0.1	$<$0.1
Cu	0.5	0.4	0.5
Fe	6.6	4.2	40.1
Mn	0.1	0.1	0.2
Ni	$<$0.1	$<$0.1	$<$0.1
Pb	$<$0.5	$<$0.5	$<$0.5
Zn	1.0	0.7	0.8

The various responses observed during the experiment, such as plant growth and uptake of nutrients, were evaluated for statistical significance by Duncan's new multiple-range test.Effects were considered significantly different at the 95 percent confidence level.

RESULTS

Sludges were obtained and analyzed (Table 2) four different times from the Lebanon, Ohio, sewage treatment plant. The numbers in the table are the average values of the four analyses.

The average pan evaporation rate during the experimental period was 1.6 cm/wk. Changes in weight of the pots, which indicated the evapotranspiration rate, are not reported. After the plants had germinated, differences in weight changes among pots with sludge crusts and pots without them were not significant. This indicated that water was lost mainly by transpiration rather than by evaporation. (It was observed that evaporation rates of water in pots with no plants were lower when there was a sludge crust than when there was no crust.)

The average heights of the plants during the experiment are listed in Table 3. Each value represents the average of 30 measurements, except for values from the control pots of unfertilized and fertilized plants receiving the 470-ml-water application rate; these are the average of 21 plants. Poor germination in these control pots evidently resulted from excessively wet conditions in the pots. By mistake, the pots were saturated with water at planting and were too wet throughout the germination period. Because there was an average of only seven plants per pot (instead of ten) in the control pots, the results cannot be compared with those from other treatments. Differences in height of plants from different treatments were not significant except that the fertilized plants receiving 235 ml of distilled water matured before the other plants. Consequently, they were significantly taller than the other plants between days 39 and 53.

In Table 4, the dry weights of the plants at the end of the experiment are given. Differences in fresh weight, which are not shown, paralleled differences in dry weight. The plants treated with 4,230 ml of sludge (470 ml/wk for nine weeks) yielded more grain than those treated with 2,115 ml (235 ml/wk for nine weeks). The fertilized plants receiving the 235 ml/wk water application rate produced more grain than the plants that received 235 ml/wk of any of the sludges. The low weights of the fertilized and unfertilized plants receiving the poor germination in these pots. Liming did not affect the yield of the plants. Also, the type of sludge used did not affect the yield.

In Table 5 is shown the total and extractable P in the soil. Results from the extractable P analyses showed no differences between the concentration in the soil in the upper and lower halves of the pot. Therefore, results were averaged, and each number for extractable P represents the average of six analyses. Soil samples from the upper and lower halves of the pots were mixed together, and a sample was taken for total P determinations. Hence, the values for total P are the average of three analyses.

Soils receiving the 470-ml rate of sludge had a higher total P content than those receiving the 235-ml rate. The differences were not significant, however. Similarly, although soils treated with Al- and Fe-primary sludges had higher total P concentrations than the average for all soils, the differences were not significant. The application of

TABLE 3
Height of Barley Plants Grown in a Loam Soil without Fertilizer, with Fertilizer, or with Primary, AL-Primary, and FE-Primary Sludges*

Time after planting	*No Fertilizer Unlimed*		*Fertilizer Unlimed*		*Primary sludge*				*Al-primary sludge*				*Fe-primary sludge*			
					Unlimed		*Limed*		*Unlimed*		*Limed*		*Unlimed*		*Limed*	
	235 ml/wk†	*470 ml/wk*†	*235 ml/wk*†	*470 ml/wk*†	*235 ml/wk*	*470 ml/wk*	*235 ml/wk*	*470 ml/wk*	*235 ml/wk*	*470 ml/wk*	*235 ml/wk*	*470 ml/wk*	*235 ml/wk*	*470 ml/wk*	*235 ml/wk*	*470 ml/wk*
days	cm++															
9	9	8	11	8	11	10	11	12	10	10	8	8	8	6	7	8
10	10	9	11	9	11	10	12	12	10	10	8	9	9	7	7	9
11	11	10	12	11	12	11	12	13	11	11	10	9	10	8	8	10
12	12	11	11	13	12	14	13	13	11	11	11	10	10	8	8	10
16	19	17	17	21	21	19	21	20	18	18	17	18	17	15	14	17
19	24	22	21	26	26	24	25	26	23	24	24	23	23	21	21	22
24	32	30	28	30	31	33	34	35	31	33	33	34	32	31	31	32
32	40	35	37	34	39	37	39	38	38	37	37	37	38	37	36	39
39	41	37	45	37	41	40	41	41	40	38	39	39	38	38	36	40
46	41	40	55	42	42	44	43	45	40	40	40	40	39	41	38	41
53	41	45	55	47	46	47	47	48	46	42	44	45	42	45	40	47
60	43	50	54	53	48	50	49	52	46	45	44	43	45	49	41	46
67	43	51	56	56	48	52	50	51	46	47	42	45	48	51	44	50
74	44	51	57	55	51	53	50	52	45	49	45	47	46	52	45	50
81	45	51	57	55	49	51	49	53	48	49	45	46	46	52	45	50
88	46	51	58	56	50	53	50	52	48	49	46	43	47	52	46	50
95	45	51	57	55	51	51	51	53	48	48	47	43	48	51	47	50
102	45	50	57	55	50	51	50	51	47	47	45	42	47	50	45	48
109	45	50	57	56	51	51	49	50	48	47	45	42	48	49	45	48

* In addition to the 235 or 470 ml/wk sludge or distilled water irrigations, each pot received 235 ml/wk distilled water. Day 68 was the last day sludge was added. From then until the end of the experiment, each pot received 470 ml/wk distilled water.
† Only distilled water added to these pots.
++ Average coefficient of variation: 0.15

sludge produced significant effects on the concentration of extractable P. Soils treated with unlimed Al-primary, limed Al-primary, and unlimed Fe-primary sludges, had significantly more extractable P than the other soils. Liming significantly reduced extractable P in the soil treated with Fe-primary sludges. Liming may have reduced the extractable P in soil treated with primary sludge, but significance level was less than 95 percent.

The elemental composition of the stems, leaves, and grain of the harvested plants are presented in part in Table 6. Concentration of P, N, and K in the three parts of the plants are shown for the various soil treatments and their levels. The data can be readily scrutinized for the effect of sludge loading, limed versus unlimed sludge, and the different sludge type, or fertilizer level on concentrations of P, N, and K. There is no indication of a significant effect of any of these factors. Concentrations of other elements were examined in the same fashion and similarly showed no significant effects. Median values of the concentrations for the 16 soil treatments are presented in Table 7 for all of the elements analyzed. Cd, Ni, and Pb were at low concentrations in all of the plant parts.

Changes in pH were monitored once after the primary sludge was added to the surface of the pots (Table 8). Within 24 hours after adding the unlimed sludge, soil pH had risen to the pH value of the soil with no sludge. Also, within 24 hours, the soil treated with 235 ml of the limed sludge had a pH similar to that of the control soil. After 48 hours, the soil receiving 470 ml of the limed sludge had a pH that was not higher than that of the control soil.

DISCUSSION

The results showed that barley plants irrigated with primary, Al-primary, and Fe-primary sludges grew as well as those supplied with inorganic fertilizer. Fertilized plants, however, produced more grain than plants treated with 235 ml of sludge per week. The grain yields from the plants that received the higher sludge applications approached the yield for fertilized pots. Sludge fertilized plants yielded more grain than unfertilized plants, but statistical significance at the 95 percent level could not be demonstrated.

The higher grain yield obtained with plants supplied with fertilizer as compared with plants fertilized with sludge may be the result of the different method of addition: fertilizer was mixed uniformly into the soil at the beginning of the experiment whereas sludge was added periodically over the course of the experiment and not mixed into the soil.

The growth response and grain yield for the three different types of sludge were quite similar. There is no indication that availability of nutrients (particularly P) is less from sludges that contain Al and Fe.

No discernible differences were observed between the elemental content of plants grown on sludge treated soils and the control soils with and without fertilizer. Differences in concentration and availability of the elements in the soil itself appear to have been the major factor in affecting the elemental composition of the plants. This conclusion is supported by work at Battelle-Northwest, now in progress. The Battelle results showed no significant difference in macro- and micro-nutrient concentrations between soils treated with fertilizer, unlimed sludge, or limed sludge. Nonuniformity within the soil system evidently contributes enough scatter to dominate effects of the different treatments.

The total amount of P added by the sludge and the amount of P measured in the sludge crust at the end of the 16-week experiment are given in Table 9. An average of 92 percent of the P remained in the crust. King and Morris[11], at the end of a two-year study where they added 40 cm of digested sludge to fields with coastal Bermuda grass or rye, found that the sludge crust contained 49.5 percent of the P added by the sludge. The soil contained 46.7 percent of the P, and the plants removed 3.8 percent of the P. Therefore, over a two-year period, a considerable amount of the P in the sludge crust was incorporated into the soil. It was, however, in unavailable form. Even though the digested sludge of

TABLE 4
Dry Weight of 110-Day-Old Barley Plants Grown in a Loam Soil without Fertilizer, with Fertilizer, or with Chemically-Treated Sludges

*Application rate**	*No fertilizer*	*Fertilizer*	*primary sludge*		*Al-primary sludge*		*Fe-primary sludge*	
	Unlimed	*Unlimed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*
ml/wk	grams†							
	Stems							
235	3.8	5.4	4.3	4.1	5.1	4.0	4.3	4.3
470	3.1 ++	2.4 ++	6.0	5.3	6.7	5.5	4.4	5.0
	Leaves							
235	3.0	3.7	3.3	2.6	3.0	3.4	3.2	2.9
470	2.4 ++	3.2 ++	5.2	3.9	5.1	4.5	4.9	5.4
	Grain							
235	4.3	8.3	6.1	5.3	6.4	5.7	6.5	6.1
470	3.8 ++	3.6 ++	7.3	7.7	8.0	7.4	8.2	6.5
	Total (excluding roots)							
235	11.1	17.4	13.7	12.0	14.5	13,1	14.0	13.3
470	9.3 ++	9.2 ++	18.5	16.9	19.8	17.4	17.5	16.9

*See first two footnotes Table 3.
† Average coefficient of variation: 0.10
++ Poor germination in these pots caused low yields.

TABLE 5
Total and Extractable Phosphorus in a Loam Soil with No Fertilizer, with Fertilizer, and with Primary, Al-Primary, and Fe-Primary Sludges after the Harvest of 110-Day-Old Barley Plants

*Application rate**	*No fertilizer*	*Fertilizer*	*Primary sludge*		*Al-pprimary sludge*		*Fe-primary sludge*	
	Unlimed	*Unlimed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*	*Unlimed*	*Limed*
ml/wk	ppm†							
	Total							
235	1100	980	1130	890	1510	1680	1640	1430
470	1240	1410	1440	1120	1710	2560	2070	1890
	Extractable							
235	28	39	60	32	144	137	91	60
470	32	25	46	32	147	144	95	46

* See first two footnotes under Table 3.
† Average coefficient of variation: 0.20.

TABLE 6
Concentration of P, N, and K in 110-Day-Old Barley Plants, Grown in a Loam Soil with Various Types and Levels of Sludge and Fertilizer

Factors and Levels			*Concentration of Nutrients (%) ++*								
Sludge Type	*Limed*	*Sludge Loading*	*Stem*			*Leaves*			*Grain*		
			P	*N*	*K*	*P*	*N*	*K*	*P*	*N*	*K*
None, no fertilizer	no	low*	0.15	1.19	1.69	0.10	1.62	1.78	0.29	2.25	0.95
		high*	0.11	0.72	1.65	0.18	1.37	1.87	0.31	1.53	1.16
None, fertilizer	no	low *	0.11	1.60	2.98	0.15	2.29	2.10	0.35	2.33	1.41
		high*	0.10	0.49	1.74	0.18	1.56	1.76	0.28	1.82	1.34
Primary	no	low	0.13	1.49	1.68	0.16	2.50	1.42	0.38	2.48	1.25
		high	0.16	1.94	1.48	0.11	2.19	0.98	0.44	2.68	1.17
	yes	low	0.16	1.81	2.19	0.17	2.68	1.64	0.39	2.28	1.35
		high	0.14	1.69	1.92	0.16	2.40	1.54	0.45	2.55	1.13
Al-primary	no	low	0.12	1.67	2.03	0.13	2.06	1.70	0.41	2.38	1.32
		high	0.13	2.04	1.77	0.13	2.08	1.63	0.32	2.48	1.03
	yes	low	0.10	1.50	2.49	0.16	2.44	1.91	0.30	2.42	1.17
		high	0.10	1.92	2.36	0.14	2.13	1.82	0.36	2.32	1.30
Fe-primary	no	low	0.16	1.71	1.98	0.12	2.41	2.01	0.31	2.18	1.32
		high	0.11	1.64	2.46	0.19	2.79	1.74	0.33	2.36	1.05
	yes	low	0.11	1.68	2.20	0.15	2.19	1.87	0.35	2.33	1.07
		high	0.10	1.76	2.14	0.12	2.40	1.81	0.34	2.50	1.18

* low and high loadings of water
++ mean values of 3 replicates

TABLE 7
Median Concentration of Elements in 110-Day-Old Barley Plants Grown in a Loam Soil with and without Fertilizer, and with Various Sludges

Element	*Stems*	*Leaves*	*Grain*
	percent		
P	0.12	0.15	0.35
N	1.68	2.19	2.35
K	2.08	1.78	1.18
Ca	0.38	0.59	0.08
Mg	0.10	0.28	0.12
	ppm		
Fe	80	137	54
Mn	<0.05	47	<0.05
Zn	22	21	31
B	<0.01	45	110
Al	37	41	40
Cd	<0.1	<0.1	<0.1
Ni	<0.2	<0.2	<0.2
Pb	<0.2	<0.2	<0.2

King and Morris had a higher P content than the undigested sludge used in the present experiment, the combined results show that a large amount of P fixation occurs in either the crust or the soil. Therefore, leaching of P through the soil at sludge disposal sites probably will not contribute to water pollution[11]. Runoff of extractable P could, however, contribute to pollution of surface waters. This would be particularly true for Al-primary and Fe-primary sludges because the present results showed that they have high extractable P concentrations.

Liming tended to decrease the extractable P in the soil, but the difference was not significant except for the iron-treated soil. Also, liming did not affect trace element concentration in the plants. With time, liming would probably affect P availability, as well as trace element availability. Many trace elements in limed sludge would be expected to become less soluble than those in unlimed sludge. Whether liming increases or decreases P availability would depend on the pH of the soil. If the addition of sludge raised the pH of an acid soil to pH 6.5, P availability probably would increase. pH values greater than 6.5 would be expected to reduce the availability of P[2]. On soils with a pH value above 7.0, little soil pH change would be expected after adding limed sludge[2]. Organic matter in the sludge also would influence concentration and availability of P and trace elements in sludge. At high rates of sludge application, use of limed sludge could be advantageous to keep P and trace elements as unavailable as possible if there were a danger of water pollution.

It is possible that the Al and Fe compounds present in sludge may be sufficiently reactive to bind phosphate and trace elements. Long-term testing would be required to determine such an effect.

In this experiment, the fertilized plants (235-ml-water application rate) grew the best at the beginning of the experiment. However, the final height of the plants from the different treatments were similar at the end of the experiment. The early rapid growth of these fertilized plants may have been due to the readily-available nitrogen in the fertilizer. For the sludge-treated plants, however, the N in the sludge (about three percent of the dry solids) was provided as the sludge was added weekly to the soil. These plants increased in growth rate as N was added.

Even though there was no difference in the N content of the plants receiving the limed and unlimed sludge treatments, the N content of the soil receiving the sludge probably was lower than that of the soil receiving the unlimed sludge. The Battelle-Northwest studies, mentioned previously, have shown that ammonia-N concentrations in limed primary sludge (pH 12) were more than 50 percent less than those in raw primary sludge (pH of 6.0 to 6.5). In the raw sludge, ammonia was present as the ammonium ion (NH_4^+). But after lime treatment, ammonia existed as the dissolved gas (NH_3) which volatilized. In long-term studies, the low N content of limed sludges might be just as important, or more important, as the P content in controlling the growth of the plants.

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TABLE 8
pH of a Loam Soil after Application of Limed (pH 11.8) or Unlimed (pH 5.7) Primary Sludge

Depth of soil sample in pot	*pH of sludge*	*Sludge application*	*Time after sludge application*		
cm		ml	hr		
			2	24	48
0-7	5.7	235	. . .	7.8	7.6
7-14	5.7	235	. . .	7.9	7.7
14-21	5.7	235	. . .	7.9	7.7
0-7	5.7	470	6.6	7.9	7.8
7-14	5.7	470	6.5	7.9	7.8
14-21	5.7	470	6.7	7.7	7.8
0-7	11.8	235	8.7	7.6	7.2
7-14	11.8	235	8.7	7.9	7.3
14-21	11.8	235	8.7	7.9	7.2
0-7	11.8	470	8.8	8.0	7.3
7-14	11.8	470	8.8	8.1	7.4
14-21	11.8	470	8.8	8.0	7.4
0-7	No sludge added		7.8	7.8	7.4
7-14	" " "		7.8	7.9	7.5
14-21	" " "		7.8	7.8	7.6

TABLE 9
Total P Added by Sludge or Fertilizer to a Loam Soil in which Barley Was Growing and the P Content of the Sludge Crust at the End of the 110-Day Growth Period

Treatment	*P added by sludge or fertilizer*	*P in sludge crust at harvest*	*Change in P content of crust*
	grams		%
No fertilizer, 235-ml rate (water)		. . .	
" " 470-ml " "	. . .	. . .	
Fertilizer 235-ml " "	1.96	. . .	
" 470-ml " "	1.96		
Primary, unlimed sludge, 235-ml rate	0.39	. . .	
" " " 470-ml "	0.77	. . .	
" limed " 235-ml "	0.39		
" " " 470-ml "	0.77	. . .	
Alum-Primary, unlimed sludge, 235-ml rate	1.13	1.14	101
" " " " 470-ml "	2.26	2.54	112
" " limed " 235-ml "	1.13	1.10	97.4
" " " " 470-ml "	2.26	2.24	99.1
Iron-primary, unlimed " 235-ml "	1.17	0.89	75.6
" " " " 470-ml "	2.34	1.77	75.6
" " limed " 235-ml "	1.17	1.21	103
" " " " 470-ml "	2.34	1.70	72.6

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UTILIZATION OF DIGESTED CHEMICAL SEWAGE SLUDGES ON AGRICULTURAL LANDS IN ONTARIO

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INTRODUCTION

Sewage sludge is a by-product of the sewage treatment plant process and its subsequent treatment and disposal is considered to be the most costly phase of sewage treatment. Although a number of alternatives exist for the handling of sewage sludge, the predominant method used in Ontario involves anaerobic digestion followed by dumping into sanitary landfills or disposal onto farmers' fields.

Keeping in step with the overall concept of recycle, reuse and reclamation, Ontario is now recommending, wherever possible, the utilization of digested sewage sludge on articultural lands.

Interim guidelines and regulations governing sewage sludge application to agricultural lands have been established by the Ontario Ministry of the Environment in conjunction with agricultural and health concerns. Through provision of adequate controls and continual upgrading as new technology is developed, these guidelines and regulations will ensure that this practice may be pursued with maximum benefit while minimizing hazards of soil, crop and ground and surface water contamination.

Sludge Production

With a population of some 7.7 million people (1971 Census), Ontario has a total of some 360 sewage treatment plants of which 230 are mechanical, primary or secondary plants (71 percent are secondary) with the remainder being lagoons. The largest plant has a design capacity of 180 MIGD, only six percent of the plants have a capacity greater than 10 MIGD and 71 percent have a design capacity of 2.0 MIGD or less.

If one assumes that sludge production from sewage treatment is equivalent to 0.5 percent of the flow, there are approximately 4.3 million gallons of sludge at from three to six percent solids produced per day in Ontario which must be suitably disposed of. The cities of Toronto, Hamilton, London and Ottawa account for about 50 percent of the sludge production.

Ontario has two basically different kinds of sludge disposal problems. The highly populated metropolitan areas produce massive volumes of sewage sludge and cost of transportation and difficulty of finding suitable disposal sites are major factors in the choice of sludge disposal systems at their relatively large sewage treatment plants. At the small sewage treatment facilities dispersed throughout the remainder of the Province, disposal sites can usually be found within realistic travelling distances and any form of sludge thickening or dewatering generally only adds to the disposal cost.

Present Sludge Disposal Practices

Present sludge disposal practices used in Ontario include incineration, lagooning, dumping into sanitary landfills, disposal onto farmers' fields, and drying and stockpiling for home garden usage. Metro Toronto, Hamilton and London each have sludge incinerators and between them incinerate approximately 41 percent of the sludge produced in Ontario. About 70 percent of the remainder of the sludge is disposed of onto farmers' fields.

For the major percentage of the sewage treatment plants in Ontario, land application of the sludge is perhaps the most satisfactory solution to the sludge disposal problem. It is not necessarily cheap, averaging out at about $32.00 per ton dry solids when compared to reported incineration costs ($10 to $50 per ton dry solids total U.S.) but for a small municipality incineration is out of the question.

Although land application is the most common method of sludge disposal in Ontario, in most instances it is looked upon as a disposal rather than a utilization practice. Sludge application rates used are generally higher than they should be and the farmers, although realizing the benefit from the sludge, seldom take into account the nitrogen and phosphorus so added when applying commercial fertilizers.

Agricultural Value of Sludge

The value of sewage sludge as a fertilizer and soil conditioner has been well documented. Sewage sludges have a favourable effect on soil properties by increasing field moisture capacity, non-capillary porosity, cation exchange capacity, organic matter content and soil aggregation. All of these factors tend to render the soil more suitable to plant growth through improved aeration, greater ease of root penetration, increased rate of water infiltration and improved availability of nutrients.

As a fertilizer, sewage sludge contains on the average, about four percent nitrogen and two to three percent phosphorus by weight. An application of three to four tons of sludge per acre will provide adequate nitrogen and phosphorus for a healthy crop of corn. One thousand gallons of sludge will have a fertilizing value of about $7.50. Sewage sludges also contain varying amounts of potassium and other macronutrients essential for plant growth.

One must not, however, overlook the possible dangers involved in its usage and its misuse. Besides containing the major nutrient materials, sewage sludge also contains varying concentrations of heavy metals and complex organic compounds which could lead to crop contamination and soil and water pollution.

Probably the greatest concern in Ontario at present in the agricultural utilization of sewage sludges relates to their heavy metal content and the possible long term effect these metals may have on the soils, crop and subsequent food chain.

Although several of the heavy metals contained in sludge are considered to be essential for plant growth, and some Ontario soils are naturally deficient in one or more of these metals, there is often a narrow margin of concentration between when an element is a nutrient and when it becomes a toxicant. In addition, many of the metals contained in sludges are non-essential to plant life and their presence in the soil must be viewed with suspicion.

Nitrogen, if applied in excess to the soil, may readily leach out into the groundwater. Phosphorus on the other hand is tied up in mineral soils in the uppermost layers of the soil. If the soil phosphorus level is permitted to build up too high, soil erosion and runoff may contribute high levels of phosphorus to the receiving stream. Sludge application rates must therefore be geared towards optimum usage of these nutrients by the crop.

Ontario's Phosphorus Removal Program

As a result of the 1969 International Joint Commission report[1] recommending that phosphorus discharges from all sources in the Lower Great Lakes be reduced to the lowest practical level, the Province of Ontario announced a policy requiring the installation of phosphorus removal facilities at municipal and institutional wastewater plants in both the Lower Great Lakes areas and in inland recreational waters.

Initially, the policy required a minimum removal of 80 percent of the phosphorus from wastewater plant influents with the need for higher levels of removal to be determined by further studies of the receiving waters. This criterion was subsequently superseded in the Lower Great Lakes by the signing, in April, 1972, of the Canada-United States International Agreement on Great Lakes Water Quality[2] which called for an effluent objective of 1 mg/1 total phosphorus.

Permanent phosphorus removal facilities must be operational by December 31, 1973 in the most critically affected areas of the Province, by December 31, 1975 for those facilities discharging to waters deemed to be in a less critical condition, and three years after notification in all other areas of the Province where problems are found to exist. Figure 1 outlines the scheduled phosphorus removal compliance dates for the southern section of the Province of Ontario.

Under this program, approximately 100 mechanical plants are affected by the 1973 date, and a further 50 by the 1975 date, leaving 72 for future notification.

Land disposal of sewage sludges has been practiced in Ontario for many years without the identification of any specific problems. The ultimate disposal of sludge was generally of no concern to the sewage treatment plant operator, however, and

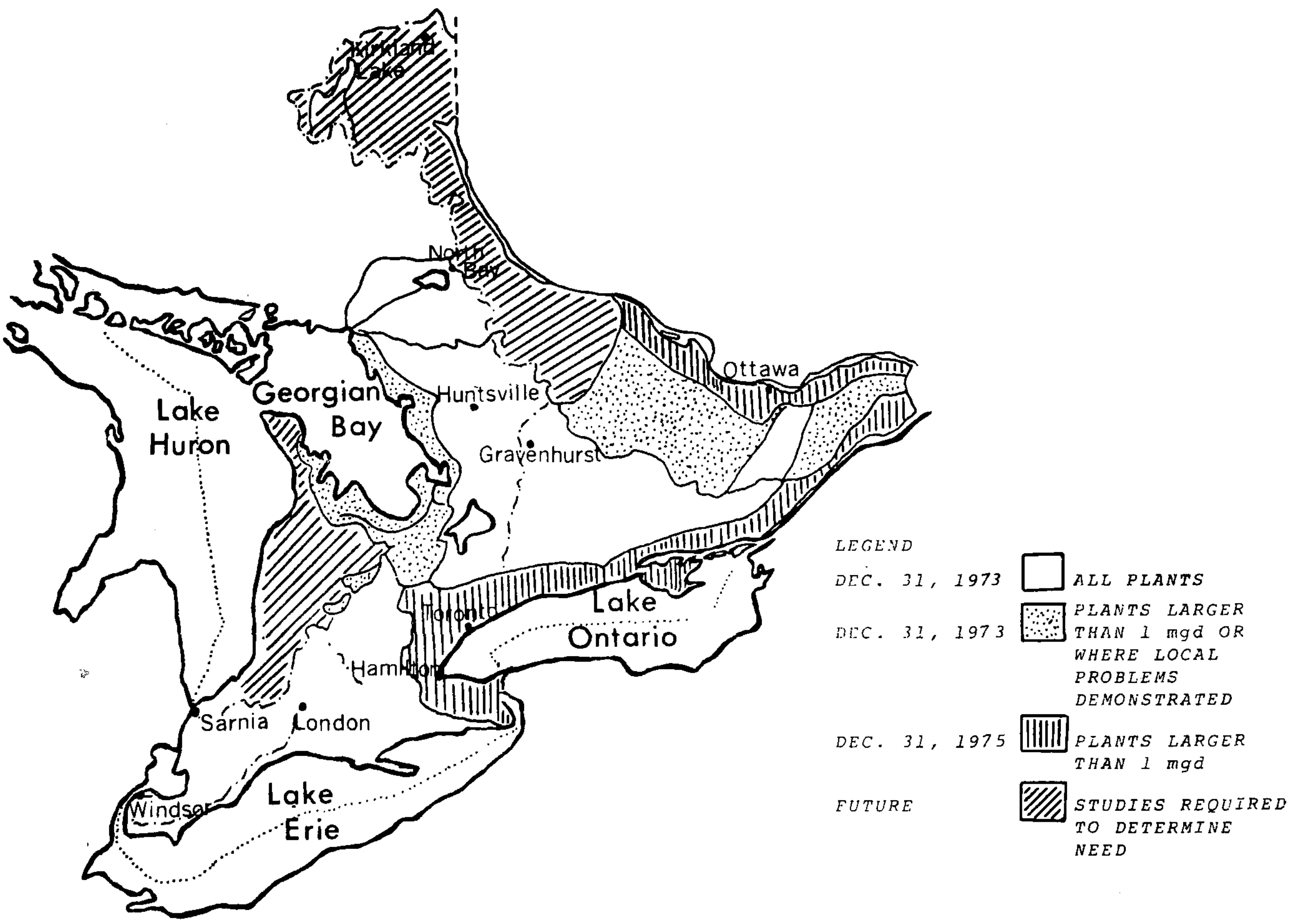

Figure 1: Province of Ontario—Southern Section. Phosphorus Removal Program Scheduled Compliance Dates.

no particular effect was placed on evaluating this method of disposal.

With the onset of the Province-wide phosphorus removal program, however, whereby about 85 percent of all the sewage treatment facilities in Ontario will be practicing phosphorus removal by the end of 1975, a much closer look is now being taken at this method of disposal with a strong emphasis on utilization. More consideration is being given to the benefits and hazards involved with the sludge contained nutrients, heavy metals, long chain organics and the micro-organisms on soils, crops and ground and surface waters.

Chemical Sludges for Land Utilization

As all phosphorus removal facilities in Ontario will employ chemical precipitation processes, considerable concern has been expressed as to the acceptability of the chemical sludges so produced for land utilization.

The use of chemicals in sewage treatment increases the weight of solids produced, generally increases the volume of sludge to be disposed of and alters its composition. The chemicals will precipitate out more of the heavy metals and phosphorus and will affect the nitrogen fractions and the sludges become more chemical in nature. The metals used for phosphorus precipitation, aluminum, iron and calcium are themselves however, abundantly found in natural soils and the extra sludge solids will tend to dilute the extra metals and phosphorus precipitated. Thus, it is felt that when considering their effects on agricultural soils, normal and chemical sludges may be treated alike, except for possible effects on nitrogen availability and sludge decomposition rates.

Because of the desire to ensure the acceptability of the practice of digested sewage sludge utilization on agricultural land, the governments of Canada and Ontario are supporting a comprehensive program of coordinated studies on sewage sludges under the Canada/Ontario Agreement on Great Lakes Quality[3].

Canada/Ontario Agreement Research

Under the Canada/Ontario Agreement[3], joint funding has been provided by the governments of Canada and Ontario for the upgrading of sewage treatment facilities in the Lower Great Lakes Basin. A total of six million dollars has been provided over a five year period to conduct related research studies.

One of the areas of high priority for research work involves sludge treatment and disposal, and a total of seven projects dealing with sewage sludge utilization on agricultural lands are being funded. These projects may be divided into the five main areas as listed in Table 1.

TABLE 1
Research Projects - C/OA

1 - *Characterization of Sewage Sludges*
Nutrients
Heavy Metals
Organic Compounds
Virus
2 - *Laboratory & Greenhouse Studies*
Heavy Metal Availability
Sludge Decomposition
3 - *Field Trial Studies*
Plant Uptake
Runoff
4 - *Lysimeter Studies*
5 - *Application Equipment*

Projects are well underway in attempting to characterize sewage sludges as to variability both within a single source and between different sources in relation to heavy metals, organic compounds and viruses as well as nutrients.

Laboratory and greenhouse studies are being carried out in an attempt to determine the rate of decomposition of sewage sludges in soils as affected by the availability of nitrogen and the soluble-insoluble relationships of heavy metals. Extractants are being evaluated for one which may be used to determine the crop available portion of heavy metals under specific soil environments.

Long term field studies have been initiated to determine the maximum rate of sludge application on an annual and perennial crop, as influenced by soil texture, which will maintain crop quality and yield and avoid contamination of groundwater. Long term runoff studies are also being carried out in an attempt to relate sludge application rate to the quality of runoff from two different slopes.

Lysimeter studies are being funded to determine the environmental effects of chemical sludge disposal on land including effects on soil properties, plant growth and the transport of organic and inorganic constituents of chemical sludges within soils and to groundwater.

A further study evaluating various types of application equipment in relation to the physical damage of wet soils has now just been completed.

Out of these studies it is anticipated that regulations may be drawn up to effectively control the utilization of sewage sludge as an organic fertilizer on agricultural land without adversely affecting soil, crop, ground or surface waters with nutrients, heavy metals, organic materials or pathogenic organisms.

Guidelines on Land Utilization of Sewage Sludges

Until the current studies of the land utilization of sewage sludges are completed, it would be inopportune to establish firm regulations concerning this method of sludge disposal. Therefore, the Ministry of the Environment, in consultation with the Ministry of Agriculture and Food, University of Guelph and Ministry of Health has adopted a set of interim guidelines to be used in the meantime. Ultimately, some of these guidelines will be added to regulations which already exist concerning the location and management of the site.

The interim guidelines cover the items as listed in Table 2 and are outlined in Appendix A. Guidelines are also being prepared in relation to the heavy metal content of the sludge. Under these new guidelines, there will be acceptable and non-acceptable sludges for land application. Non-acceptable sludges will be those which contain one or more heavy metals in excess of maximum allowable concentrations. A maximum allowable concentration in the sludge for each metal will be set from a knowledge of the heavy metal content of

TABLE 2
MOE Interim Guidelines

1 - Site Location
2 - Land Characteristics
3 - Site Management
4 - Application Rates
5 - Application Equipment

domestic sewage sludge and the degree of treatment available for the various industrial wastes contributing heavy metals to municipal wastewaters. Such a guideline should provide a positive incentive to the municipalities to enforce industrial bylaws covering industrial discharges to sewers as well as protecting the agricultural lands where sludges are applied.

REFERENCES

1. "Pollution of Lake Erie, Lake Ontario and the International Section of the St. Lawrence River," Volume 1, Summary, International Joint Commission, 1969.
2. Canada/United States International Agreement on Great Lakes Quality, April, 1972.
3. Canada/Ontario Agreement on the Lower Great Lakes, August, 1971.

APPENDIX A

Guidelines for Utilization of Processed Organic Waste by Land Application

NOTE:

a) The following pertains to the utilization of processed organic waste which has undergone proper anaerobic or aerobic digestion or other suitable processing at a municipal water pollution control plant.

b) It is intended that the method of land application entail the utilization of processed organic waste in the agricultural industry, as opposed to merely disposing of the material.

Emphasis should be placed on the aspect of utilization as stated, embodying the proposed principles relating to rates of applications, since these will markedly reduce the potential for run-off loss. It is suggested that the lower limit of a range be used on sloping land. For minimum distances to water course, use same figures for winter as for summer.

1. *SITE LOCATION*

1.1 The site should be remote from surface water courses. The minimum distance between the site and the surface water course should be determined by the land slope as follows:

Maximum Sustained Slope	Minimum Distance to Watercourse	
	For processed organic waste application during May to Nov. inclusive	For processed organic waste application during Dec. to Apr. inclusive
0 to 3%	200 feet	600 feet
3 to 6%	400 feet	600 feet
6 to 9%	600 feet	No processed organic waste to be applied
greater than 9%	No processed organic waste to be applied unless special conditions exist	No processed organic waste to be applied

1.2 The site shall be at least 300 feet from individual human habitations.

1.3 The site shall be at least 300 feet from water wells.

1.4 The site shall be at least 1,500 feet from areas of residential development.

1.5 No spreading shall be done when there is more than 3 inch frost or a solid ice layer on the surface of the soils, particularly when there is no snow cover. (It is considered that waste applied to a snow cover when there is little or no frost in the soil below the snow will be relatively safe from run-off.)

1.6 Above values are for rapid to moderately rapid permeability. For moderate to slow permeability the distances should be doubled and spreading suspended during March and April when run-off is expected. Use footnote from item 2 to determine permeability classification.

1.7 In Northern Ontario suspend spreading on moderate to slowly permeable soil during April and May.

1.8 The groundwater table during processed organic waste application should be not less than 3.0 feet from the surface for soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability, the groundwater table should be not less than 5.0 feet from the surface.

2. *LAND CHARACTERISTICS*

2.1 The land slope and soil permeability will determine the time of year that processed organic waste may be applied as follows:

3. *SITE MANAGEMENT*

3.1 When sludge is applied to agricultural land, the land is to be for those crops specified in these Guidelines. Dairy cattle should be excluded from pasture land. These restrictions on land use shall apply from the date of application until the end of the calendar year during which the processed organic waste has been applied.

3.2 The boundaries of the site shall be marked (e.g. with stakes at corners) so as to avoid confusion regarding the location of the site during processed organic waste application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

3.3 Soil tillage and processed organic waste application should where possible, follow the contours of the land (to maintain a contour furrow system). Passage of processed organic waste spreading vehicles over the land should be minimized to reduce compaction of the soil (e.g. the allowable processed organic waste application rate in cu. yds./A/yr., could be achieved after one or two passes).

3.4 Special precautions may be required where the possibility of localized surface water runoff problems exist.

Max. Sustained Slope	Soil Permeability*	Allowable Duration of Application	
		Southern Ontario	Northern Ontario
0 to 3%	any	12 mo/yr	12 mo/yr
3 to 6%	rapid to moderately rapid	12 mo/yr	12 mo/yr
	moderate to slow	10 mo/yr (May to Feb.)	9 mo/yr (June to Feb.)
6 to 9%	rapid to moderately rapid	7 mo/yr (May to Oct.)	6 mo/yr (June to Oct.)

*Soil permeability classification shall be in accordance with Tables 1 and 2 of the Ministry of Agriculture and Food's publication entitled "Drainage Guide for Ontario." The type of soil should be determined with the use of County Soil Maps available through the Ministry of Agriculture and Food

Organic wastes are best applied to unplowed soil with the residues of the previous crop present to control runoff. This is particularly useful for winter spreading.

3.5 Where processed organic waste application is carried out by tank truck, untiled land should be given preference to tiled land. Where tiled land is used the processed organic waste hauling contractor should request instructions from the landowner, with regards to minimizing the possibility of damage to the tile system.

4. *PROCESSED ORGANIC WASTE APPLICATION RATES*

4.1 In determining the allowable rate of processed organic waste application for a particular parcel of land, the objective shall be to match as closely as possible the quantity of nutrients removed from the soil by the harvesting of the crop. The allowable rate will thus be determined by the nutrient content of the particular processed organic waste and the nutrient uptake capabilities of the particular crop under consideration. The processed organic waste hauling contractor shall adhere to the application rate (in cu. yd./A/yr.) specified in the Certificate of Approval issued by the Pollution Control Planning Branch of the Ministry of the Environment. The suitability of processed organic waste application rates may, if required, be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Pollution Control Planning Branch.

4.2 The processed organic waste shall be spread uniformly over the surface of the land.

4.3 The water pollution control plant operating agency is to keep records of the location of all the sites used for the disposal of its processed organic waste and the processed organic waste quantities disposed of at each site, each week (e.g. Volume of processed organic waste in cu. yds., and weight of processed organic waste solids in tons). The operating agency shall ensure that at least every 2 months, samples of the processed organic waste are submitted for thorough analysis (e.g. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, ether extractables, heavy metals, etc.).

5. *PROCESSED ORGANIC WASTE HAULING AND SPREADING EQUIPMENT*

5.1 Equipment should be maintained in good working order at all times and should be cleaned on a regular basis.

5.2 Before the tank can be used for any other purpose, permission must be obtained from the appropriate authority such as, the Pollution Control Planning Branch, the Ministry of Health, the local Medical Officer of Health, etc.

5.3 The processed organic waste should be spread at least as wide as the widest part of the spreading equipment to minimize the number of passes required to spread the processed organic waste on the site.

5.4 Some method should be provided to control the spreading valve by the driver of the spreading equipment while the vehicle is in motion.

5.5 The spreading valve should not be opened until the spreading equipment is in motion.

5.6 The spreading valve should be of the "fail safe" type (i.e. self-closing) or an additional manual stand-by valve should be employed to prevent the uncontrollable spreading or spillage of the processed organic waste.

5.7 Care should be taken under windy conditions to avoid spreading out of the approved area.

5.8 The hauling equipment should be so designed to prevent the possibility of spillage, the dissemination of odours, and other public nuisances during transport.

5.9 If the processed organic waste is transferred from the hauling equipment to separate spreading equipment, the transfer should be carried out under controlled conditions to preclude spillage, perhaps using a closed-type transfer system.

5.10 Backup equipment should be readily available in the event of breakdown of equipment on the highway or site.

5.11 A pumped or pressurized spreading method must be considered the preferred technique to obviate an even and consistent spreading of the processed organic waste on the site.

THE ECONOMICS OF SLUDGE IRRIGATION

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The existing plant of the Springfield Sanitary District was completed and placed into operation in 1928. Since that time, the District has utilized several of the commonly used methods of anaerobic sludge disposal, including sludge drying beds and shallow sludge lagoons. Because of the decreased demand for municipal sewage sludge in the early 1960's and a considerable change in farming practices in the area, the District decided to experiment with disposal of the sludge on our own land. It was reasoned that it would be more economical to apply it to our land in the liquid state and thus save the cost of bulldozing the sludge from lagoons, loading it, hauling it and spreading it in the dry state on our own land.

A plot of approximately eight acres of very poor agricultural land was set up for test purposes. A road was built, the land was cleared, ravines were filled and a pipe line was built from the digester area to the sludge disposal area. Discharge of sludge to the experimental plot was begun in 1965.

Without resorting to a recital of the various problems encountered in the course of this experimental work, it nevertheless becomes obvious that the development of this process of sludge irrigation was arrived at by rationalization of a logical sequence of sludge disposal methods. Since funds were not available for a highly scientific study, it was necessary that we carry on our studies in a most rudimentary manner and within the very limited funds available to the District for this purpose. We made our mistakes as we proceeded and corrected them as best we were able. Through all of this trial and error operation, it still became obvious that liquid disposal of anerobically digested sludge to the land was a feasible and economic method of sludge disposal.

While a project such as this is designed primarily as a means of disposal of sludge, one of the side benefits from it is the fertilization and buildup of the soil to the point where a better crop yield is obtained. Records were kept on the yield from the area on which sludge was applied as compared to an area immediately adjacent on which sludge was not applied. These are summarized in Table 1. During the crop year 1965, a yield of 107 bushels of corn per acre was obtained from the area on which liquid sludge was applied as compared with a yield of 88 bushels per acre on the adjacent area with no sludge. This worked out to a net dollar yield per acre of $65.19 for that area receiving the sludge. The increased yield in dollars per acre as compared to the adjacent land was $18.05 per acre. During the year 1966, the crop was not as good throughout the entire area. A yield of 76 bushels per acre was obtained from the area on which sludge was applied as compared to the yield of 39 bushels per acre on the area receiving no sludge. This resulted in a net dollar yield per acre of $49.02. The increased yield in dollars per acre was $44.03. During the year 1967, it was disasterous climatically for this type of operation. A wet spring delayed planting to the point where corn could not be planted on the test plot because of the lateness of the season. As a result, soybeans were planted on four of the five terraces, the fifth being too wet to plant. A wet summer produced an excellent crop; however, an extremely wet fall prevented harvesting of the crop and the soybean crop was ultimately abandoned and left in the field. As a result, there is no com-

TABLE 1
Tabulation of Crop Yields and Sludge Application

Crop Year	Crop Yield-Bu/Ac. Sludge Irr. Area	No Liquid Sludge Area	Increase Crop Yield Bu/Acre	Net $ Yield Per Acre	Corn Price $/Bu.	Increased $ Yield Per Ac. of Liquid Sludge Area Over Other	Actual Acres Planted	Sludge Applied Thousand Gallons	Tons D.S. Per Acre	Cost Per Ton of Dry Sol.
1965	107	88	19	$65.19	$0.95	$18.05	7	3,415	106	$0.97
1966	76	39	37	49.02	1.19	44.03	7	2,360	67	1.77
1967*				-20.00			0	290	11**	17.05
1968	62	32.5	29.5	**7.07	0.897	26.46	4	1,105	36**	4.46
1969	82.6	70.5	12.1	**9.86	0.954	11.54	2.9			
1970										
1971							0	2,260	64	2.62
Avg.	81.9	57.5	24.4	$22.23	$0.998	$25.02	5.2	1,886	56.8	$2.46***

*Terraces tiled at cost of $8,005.73
**Based on 7 acres
***Excludes 1967 data in average

parison during the year 1967 and the net dollar yield per acre was a minus $20.00 because of the expense occurred in planting the crop and the fact that it was not harvested. During the year 1968, four out of the seven acres were planted in corn with the other three being utilized for sludge disposal. Also, dried sludge removed from the sludge lagoons had been applied to the adjacent land to build up its fertility, so the direct comparison with sludged and unsludged land did not apply as well. However, there was a yield during the 1968 season of 62 bushels per acre on the area on which liquid sludge had been applied as compared to 32.5 bushels per acre on the adjacent land. This resulted in a dollar yield per acre of $7.07 as spread over the entire seven acre test plot. It also would have amounted to an increased yield of $26.46 per acre based on the actual acres planted in corn in that year. During the year 1969, 2.9 acres out of the seven acre plot were planted in corn; the other four acres being utilized for sludge disposal. Dried sludge had continued to be applied to the adjacent land to build up its fertility. The land with liquid sludge application had a yield of 82.6 bushels per acre of corn during that year as compared to 70.5 bushels on the adjacent land without the liquid sludge. This resulted in a dollar yield per acre of $9.86 when spread over the entire seven acre test plot. The increased yield amounted to $11.54 per acre based on the actual acres planted. During the year 1970, no comparison between the two areas is available. Crops were not planted in the entire area for the year 1971 because of the imminence of construction in this particular area. Average production on the sludged areas over the four years of record was 81.9 bushels of corn per acre while on the unsludged area it was 57.5. This is an increase in yield of 42 percent. It may be concluded that while the dollar value of crops harvested is a factor to be reckoned with, it is not a controlling factor in the operation of such an area.

The basic reason for operation of a liquid sludge disposal area is, of course, disposal of sludge. During the period March 1965 through February 1966, a total of 3,415,000 gallons of sludge or 1,695,400 pounds of dry solids were applied to the test plot. This amounted to 211,925 pounds of dry solids per acre of 106 tons per acre. This was applied during the period July 1 to September 1. Corn had been planted in the plot and sludge was not applied until the corn was approximately 18 inches high and had been cultivated once. It was then applied by running it down the corn rows as often as the ground was dry enough to take it. This was discontinued on September 1 to allow the field to dry for harvesting. After harvesting in November, the land was plowed and disced and sludge applied through the winter until March 1 when it was discontinued to allow the land to dry for planting.

The period March 1966 to February 1967 was not as favorable climatically for this type of operation as was previously explained. In spite of the poor year during this period, a total of 2,360,000 gallons of sludge or 1,075,925 pounds of dried solids were applied to the test plot. This amounted to 134,491 pounds of dried solids per acre or 67 tons per acre.

It was pointed out previously that the period March 1967 to February 1968 was disastrous climatically for this type of operation. Some sludge was applied to the test area; however, this amounted to a total of 290,000 gallons or 157,201 pounds of dry solids. This was only applied on the fifth terrace, the other four terraces being planted in soybeans which could not be irrigated with sludge during the growing period. Using these figures over the entire test plot area, this amounted to 19,650 pounds of dry solids per acre or 10 tons per acre disposed of on the test plot.

During the period March 1968 to February 1969, 1,105,000 gallons of sludge were applied on three of the seven acres of the test plot, the other four acres being utilized for crop production. A total of 503,805 pounds of dry solids were applied or 71,972 pounds or 36 tons per acre of dry solids when applied over the entire seven acre tract.

The years March 1969 to February 1970 and March 1970 to February 1971 were not reported on as previously explained. During the year March 1971 to February 1972, no crop was planted on the area because of anticipated construction. However, sludge was continued in application over the entire seven acres. A total of 2,260,000 gallons of sludge were applied during this period or a total of 891,351 pounds of dry solids. This worked out to an average of 127,336 pounds of dry solids or 64 tons applied per acre on the entire seven acre tract.

Attempts were made to make an economic analysis of the sludge disposal operation. The land had been purchased immediately prior to 1965 at a cost of $459.96 per acre. Road construction in the area to allow operations added $46.40 per acre. Clearing and filling of ravines accounted for $48.12 per acre. Terracing of the land amounted to $812.51 per acre. The pipeline to supply sludge to the area amounted to $536.46 per acre. The tiling of the terraces done in 1967 amounted to $1,143.67 per acre.

It was assumed at that time that the life of the area for sludge disposal purposes would be ten years and it was also assumed that the land would increase in value to $800.00 per acre because of building up soil fertility. If it is assumed that one-half of the cost of tiling the land is spread over this ten year period, we may then arrive at an annual cost of the land (exclusive of interest) on the investment of $459.96 plus $46.40 plus $48.12 plus $812.51 plus $536.46 plus $571.80 minus $800.00 all divided by 10 which equals $167.53 per acre.

As was previously pointed out, the net yield per acre in 1965 was $65.19. Subtracting this from the $167.53 annual cost would give a cost of $102.34 per acre as the cost of sludge disposal. Dividing the $102.34 by 106, the tons of dry sludge applied per acre, would give a cost of $.97 per ton of dry solids as the cost of sludge drying and disposal (exclusive of digestion and pumping costs).

Applying the same figures for the crop year 1966 in which a net dollar yield of $49.02 per acre was achieved and during which 67 tons of dry solids were applied per acre, we would arrive at a cost of $1.77 per ton of dry solids as the cost of sludge drying and disposal. During the year 1967, which was previously pointed out as being disastrous climatically and during which time the net dollar yield per acre of minus $20.00 was obtained and only 11 tons of dry solids applied per acre, a cost of sludge drying and disposal of $17.05 per ton of dry solids was obtained. During the crop year 1968 in which a net dollar yield per acre of $7.07 over the entire seven acres was obtained and in which sludge disposal to the extent of 36 tons of dry solids per acre over the entire seven acres was obtained, would give a cost of sludge drying and disposal of $4.46 per ton of dry solids. Again applying the same mathematics to the year 1971 in which no crop was planted or no income was received from crop and during which time 64 tons of dry solids were applied per acre, the cost of sludge drying and disposal amounted to $2.62 per ton of dry solids.

If we average the five years of 1965,'66, '67, '68 and '69, we obtain an average net yield of $22.23 per acre. Also averaging the sludge application during the years 1965, '66, '67, '68 and '71, we would arrive at an average of 56.8 tons of dry solids applied per acre. If we drop 1967, the four year average would amount to $2.46 per ton of dry solids as the cost of sludge drying and disposal.

While we experienced some very good annual results, we also experienced some disastrously poor ones. However, in spite of this, we felt that the method had application. We, in fact, had sufficient confidence in the method that it was decided after the 1968 season to go to this method of sludge disposal for the anaerobically digested sludge produced at the existing plant of the Springfield Sanitary District and to also utilize this method of sludge disposal for aerobically digested sludge at a new plant at the District.

The Springfield Sanitary District has been completed and has recently begun utilization of permanent liquid sludge application areas in two locations. An approximate 30 acre site is being utilized for this purpose at the existing Spring Creek Plant of the District. Also, a 36 acre site is being utilized for liquid disposal of aerobically digested sludge at the new Sugar Creek Treatment Works. A permanent underdrainage system is provided at each installation to carry the underflow from the sludge irrigation area back to a pump pit from which it is pumped back into the aeration tanks of the treatment works. A permanent system of force mains to allow spray irrigation of the sludge is provided. The force main system is buried at sufficient depth and valved in such manner that it can be utilized for sludge application in inclement winter weather without danger of freezing. The force main system is laid to grade so that following each sludge application, the contents of the force main will drain back to the pump pit and be returned to the aeration tanks. Both of these installations were utilized during the winter of 1973-74 and proved the feasibility of winter operation. While we do not recommend this, on one occasion we did spray irrigate sludge when the temperature was 10 degrees below zero.

Costs of developing the sludge disposal areas at these plants are possible to break down as based upon the low bid received on each contract. The itemization of the various costs involved in the sludge disposal system at the Sugar Creek Plant are tabulated in Table 2. The itemization of the costs based on the low bid at the Spring Creek Plant are tabulated in Table 3. Operation costs are nominal at the Sugar Creek Plant consisting of a small amount of operator attention (approximately one hour per week) and electric power costs. Operation costs at the Spring Creek Plant are higher because of

TABLE 2
Development Costs
Sugar Creek Sludge Disposal Area
Bid Prices of Low Bidders on Project
(Bids taken September 14, 1971)

Pumping Station			
Structure (Est. 1/3 of $94,932)		$31,644.00	
Equipment (Est. 1/3 of $36,072)		12,026.00	
Sludge Comminutor		6,352.00	
Total Pumping Station			$50,022.00
Sludge Distribution			
1,820′ of 8″ C.I. Force Main at $9.90		$18,018.00	
5,735′ of 6″ C.I. Force Main at $7.05		40,431.75	
8″ Valves - 8 at $250		2,000.00	
6″ Valves - 44 at $175		7,700.00	
Fittings - 9,415 # at $0.60		5,649.00	
Spray Nozzles 6 at $440		2,640.00	
Total Sludge Distribution System			$76,438.75
Disposal Area Underdrainage			
23,610′ of 4″ perforated PVC pipe at $2.00		$47,220.00	
1,300′ of 6″ perforated PVC pipe at $2.64		3,432.00	
640′ of 8″ perforated PVC pipe at $4.00		2,560.00	
Underdrainage Pump Pit & Controls		6,593.00	
Total Underdrainage System			$59,805.00
Miscellaneous			
4,000′ of woven wire stock fence at $2.00		$ 8,000.00	
Electrical (1/20 of $253,700 - total plant elect. bid)		12,685.00	
Total Miscellaneous			$20,685.00
Total Development Cost (Exclusive of Land)			$206,950.75
$206,950.75 / 35.73 = $5,792.07 per acre development cost of disposal area			
Land Cost			
2,075′ x 750′ 35.73 acres			
35.75 at $750 per acre land cost	$26,797.50		
	$233,748.25		
Total Disposal Area Cost			
$233,748.25 / 35.73 = $6,542.07 per acre total cost of disposal area			

TABLE 3
Development Costs
Spring Creek Sludge Disposal Area
Bid Prices of Low Bidders on Project
(Bids taken March 28, 1972)

Screening & Pumping of Sludge		
Structure	$ 6,275.00	
Equipment	15,768.00	
Total Screening & Pumping		$22,043.00
Sludge Distribution		
6,456′ - 6″ C.I. force main at $3.25	$20,962.50	
900′ - underdrain return at $8.56	7,704.00	
25 - spray irrigation headers & risers at $321.00	8,025.00	
2 - spray nozzles at $496.00	992.00	
Total Sludge Distribution System		$37,683.50
Disposal Area Underdrainage		
35,500′ - 4″ perf. PVC pipe at $2.50	$88,750.00	
1,300′ - 6″ perf. PVC pipe at $3.25	4,225.00	
2,475′ - 12″ perf. PVC underdrain at $8.30	20,542.50	
Underdrain lift station	2,657.00	
Underdrain lift station equipment	8,294.00	
Total Underdrainage System		$124,468.50
Miscellaneous		
Pipe & Foot Bridge relocation	$10,523.00	
Prevision & adjustment of bridge	365.00	
Pipe supports & Braces on bridge	1,340.00	
Electrical (1/20 of $134,939 - total plant elect. bid)	6.746.95	
Total Miscellaneous		$18,974.95
Total Development Cost (Exclusive of Land)		$203,169.95
$\frac{\$203,169.95}{30}$ $6,772.33 per acre development cost of disposal area		
Land Cost		
20 acres at $459.96 per acre	$ 9,199.20	
10 acres at $500.00 per acre	5,000.00	
Total Land Cost	$14,199.20	
Total Disposal Area Cost		
$\frac{\$203,169.95 + \$14,199.20}{30}$ = $7,245.63 per acre total cost of disposal area		

problems with the screening and pumping installation; however, they are expected to be comparable to the Sugar Creek Plant when pumping and screening problems are resolved.

Data on sludge irrigation at the Spring Creek Plant since start up are tabulated in Table 4, and similar data for the Sugar Creek Plant are tabulated in Table 5. The data in both instances has been computed on a per acre per year basis to allow for comparison with installations elsewhere. It will be noted that a much heavier hydraulic application was made in the case of the aerobically digested sludge, as would be expected, but the pounds of solids applied per acre were in reasonably the same range. The anaerobic sludge was applied at a rate approximately 4-¾ inches depth per year compared to the aerobic sludge application of 14-½ inches depth per year. The anaerobic sludge was applied at the rate of 27 tons per acre per year of dry solids compared to 22-½ tons for the aerobic sludge.

We are well aware that there are many questions yet to be answered with regard to this method of sludge disposal. Answers to these questions will evolve as more experience is obtained by ourselves and others. We believe that because of the underdrainage system, we are in a position to collect data on this method of sludge disposal that no other present installation has available to them. We are, therefore, planning on an extensive data collection project at both plants which we would hope to report on at a later time. Hopefully, this will be helpful in answering some of these questions.

TABLE 4
Spray Irrigation of Anaerobically Digested Sludge at Spring Creek Plant

Date	Gallons	% *Solids*	% *Volatile*	*Lbs. Solids*	*Lbs. Volatile*
10/16/73	60,000	5.38	41.6	26,922	11,199
10/17/73	60,000	4.93	43.1	24,653	10,609
10/18/73	50,000	4.92	43.2	20,516	8,872
10/19/73	60,000	4.80	41.9	23,994	10,057
10/22/73	80,000	4.89	42.6	32,635	13,822
10/23/73	70,000	4.92	48.7	28,740	14,051
11/1/73	80,000	5.24	43.8	34,995	15,324
11/2/73	80,000	4.87	44.3	32,500	14,382
11/15/73	80,000	4.92	42.3	32,876	13,916
11/19/73	70,000	5.68	44.1	33,185	14,629
11/28/73	60,000	5.27	45.0	26,371	11,868
11/30/73	15,000	4.75	38.5	5,942	2,288
12/1/73	40,000	5.16	46.2	17,196	7,932
12/7/73	80,000	4.90	45.3	32,693	14,811
12/13/73	40,000	4.67	40.3	15,562	6,276
12/26/73	120,000	5.25	44.6	52,492	23,382
12/27/73	60,000	5.42	46.0	27,121	12,478
12/28/73	50,000	5.18	45.5	21,601	9,828
1/15/74	230,000	5.24	42.4	100,580	42,585
1/16/74	180,000	4.57	47.6	68,672	32,722
3/4/74	100,000	4.99	45.4	41,649	18,907
3/28/74	100,000	4.92	43.7	41,033	17,929
Total	1,765,000			741,928	327,867
Average		5.04	43.9		
Annual Per Acre Average	129,360			54,378	24,030

TABLE 5
Spray Irrigation of Aerobically Digested Sludge at Sugar Creek Plant

Date	*Gallons*	% *Solids*	% *Volatile*	*Lbs. Solids*	*Lbs. Volatile*
10/3/73	43,000	1.30	51.3	4,654	2,388
10/5/73	298,000	1.41*	52.7*	35,039	18,465
10/9/73	170,000	1.41*	52.7*	19,980	10,529
10/18/73	85,000	1.41*	52.7*	9,983	5,261
10/19/73	85,000	1.41*	52.7*	9,983	5,261
10/29/73	213,000	1.41*	52.7*	25,042	13,197
10/31/73	43,000	1.41*	52.7*	5,048	2,660
11/12/73	341,000	1.19*	54.9*	33,832	18,574
11/13/74	128,000	1.19*	54.9*	12,697	6,971
11/16/73	107,000	1.19*	54.9*	10,615	5,828
11/19/73	107,000	1.19*	54.9*	10,615	5,828
11/27/73	107,000	1.19*	54.9*	10,615	5,828
11/28/73	213,000	1.19*	54.9*	21,134	11,603
11/30/73	128,000	1.13	56.1	12,057	6,764
12/4/73	213,000	1.17	56.6	20,779	11,761
12/5/73	298,000	1.68	56.3	41,748	23,504
12/7/73	298,000	1.52	56.8	37,772	21,454
12/10/73	277,000	1.14	57.2	26,334	15,063
12/21/73	171,000	1.78	59.4	25,383	15,077
12/26/73	320,000	1.51	60.5	40,287	24,374
1/4/74	277,000	1.14	58.8	26,334	15,485
1/9/74	319,000	1.11	59.7	29,526	17,627
1/10/74	107,000	1.13	58.2	10,080	5,866
1/14/74	107,000	1.21	60.8	10,793	6,562
1/15/74	149,000	1.19	61.2	14,780	9,045
1/18/74	234,000	1.34	63.7	26,143	16,653
1/25/74	256,000	1.45	60.9	30,958	18,853
2/1/74	288,000	1.36	57.9	32,654	18,906
2/8/74	330,000	1.39	54.8	38,253	20,963
2/15/74	341,000	1.43	55.3	40,655	22,482
2/26/74	341,000	1.53	55.7	43,498	24,228
3/6/74	332,000	1.55	53.6	42,904	22,997
3/20/74	203,000	1.76	49.8	29,797	14,839
Total	6,929,000			789,972	444,896
Average		1.35	56.07		
Annual Per Acre Average	395,437			45,084	25,390

*Average concentration of tank contents used since sampler not yet available.

SUMMARY

While there are admittedly unanswered questions, it is yet possible to define a number of a positive factors with regard to this disposal method.

1. Irrigation of cropland with liquid digested sludge is a valid method of disposal of sludges from wastewater treatment works.
2. Spray irrigation of the sludge is the most practical method of application that we have tried.
3. Irrigation of cropland with liquid digested sludge compares favorably on an economic basis with any of the presently accepted methods of sludge disposal if land is available for use of this method.
4. Operation of this method is quite simple, requiring a minimum of operation attention.
5. The method need create no odor nuisance if the sludge is reasonably well digested before application.
6. Planning of a disposal area for spray application must take into account wind drift if nuisance from this is to be avoided.
7. Establishment of a permanent disposal area with a sloped distribution system allows operation in quite severe winter weather without particular problems.
8. Provision of a good underdrainage system minimizes the possibility of ground water contamination.

9. While the method will work most advantageously in an open soil, use of the method is not confined to areas with an open soil; and it is an applicable method even in areas of a rather tight soil.

10. In this day of concern over advantageous use of our natural resources, this method is particularly attractive, since it utilizes as a resource what previously has been an odious end product of the wastewater treatment process.

COMPOSTING SEWAGE SLUDGE

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In the past, sewage sludge has been used occasionally as an additive in solid refuse (garbage) composting [1,2,4], but seldom has it been composted by itself. Recently, increased interest in sludge disposal on land has pointed up a need for more study and information on sewage sludge composting as an option in this process. Proper composting of sludge would not only dewater it and destroy objectionable odors but would also destroy any disease organisms during the compost heating process. Furthermore, compost is an aesthetic product which can be handled easily and used in urban areas.

To investigate sludge composting at a pilot plant level, studies were initiated in the fall of 1972 by the United States Department of Agriculture in cooperation with the Maryland Environmental Service and the Blue Plains Wastewater Treatment Plant in Washington, D.C. [3,5]. This project is located on the grounds of the ARS Agricultural Research Center at Beltsville, Maryland.

Composting systems generally fall into three categories: (a) pile, (b) windrow, and (c) mechanized or enclosed systems [1,2,4]. The method selected at Beltsville was the windrow system, where thermophilic microorganisms generate heat as a result of biological waste oxidation. Convective air provides microorganisms with oxygen. Convective forces cause the air to rise as it is heated. Porosity and size of windrow will determine the rate of air exchange. If the windrow is too large, dense, or wet, it may become anaerobic, thus producing undersirable odors. A small porous windrow, on the other hand, may permit such rapid air movement that temperatures remain low and composting is delayed.

The preliminary studies at Beltsville involved the use of three bulking agents—sawdust, shredded paper, and wood chips—mixed with various quantities of sludge. Twenty-two combinations of materials including both raw and digested sludge were tested. The sludge and bulking materials were mixed in approximately five cubic yard batches and stacked in a cone-shaped pile to simulate the effect of a windrow. The piles were turned every few days with a front-end loader. Temperatures and oxygen levels within the piles were monitored to determine the effectiveness of convection aeration. Bulk density and moisture content were measured to estimate the stage of composting. These tests were conducted outdoors during January, February, and March 1973. Pile temperatures were affected more by frequent heavy rains than by ambient air temperatures. All trials showed some signs of composting. The shredded paper-sludge mixtures, however, soon settled into a compact mass that air could not penetrate. Both the chips and sawdust continued to compost satisfactorily. Based on these studies, wood chips were selected as the most satisfactory bulking agent when incorporated with sludge at a volumetric chip ratio of 3:1 sludge.

Site and Operations

Figure 1 indicates the location of the composting site and the various facilities. The project covers 80 acres, of which 15 acres are used for the composting operation. The remaining area is for isolation, screening, and drainage water disposal. An aerial view of the area is shown in Figure 2. Main sections of the site are:

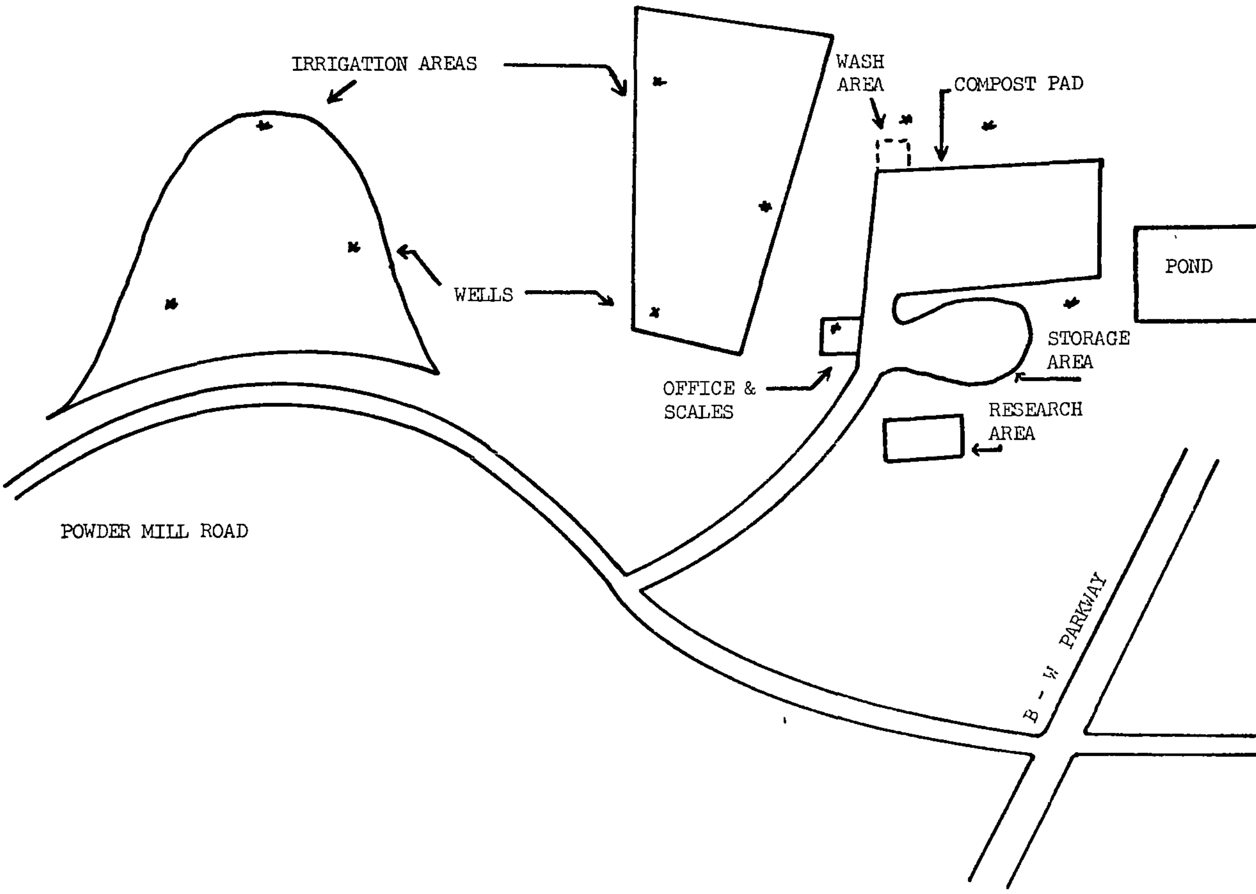

Figure 1: Composting Site, Agricultural Research Center, Beltsville, Maryland.

1. Windrow pad—a 5-acre area paved with 14 inches of crushed stone. This area can accommodate heavy equipment.
2. Wood-chip storage area.
3. Compost storage, curing, and screening area.
4. Weighing station and office building.
5. Truck wash area.
6. Runoff storage pond and irrigation disposal system. The entire site, including the pad, is graded to collect all runoff in a detention pond. Several wells were installed around the site to monitor the ground water quality.
7. Research area.

The major equipment used in the operations consists of:

1. Cobey-Terex* composter
2. LeafCo Roto-shredder
3. Screen
4. Front-end loaders
5. Dump trucks

Supplementary equipment consists of spring-tooth harrow, tractor and sprayer, irrigation system, and truck scales.

The compost operations are depicted in the flow chart (Figure 3). Details of the major operations are as follows:

1. A layer of wood chips 12 inches deep and 15 feet wide is placed on the paved area. The sludge is dumped on top of the chips and spread with a front-end loader. A ratio of three parts chips to one part sludge by volume is used. The composting machine then forms the sludge and chips into a windrow. (Either of the composting machines can be used for this operation.) Several turnings (about eight to ten times) are necessary to adequately blend the two materials.

2. The windrow is normally turned daily with the composter; however, during rainy periods, turning is suspended until the windrow surface layers dry out. Temperatures in the windrow under proper composting conditions range from 55 to 65°C. Turning mixes the surface material to the center of the windrow for exposure to higher temperatures. The higher temperatures are equivalent to temperatures needed for pasteurization and thus effectively kill most pathogenic agents. Turning also aids in drying and

*Trade names are included to provide specific information, and do not imply endorsement by the U.S. Department of Agriculture.

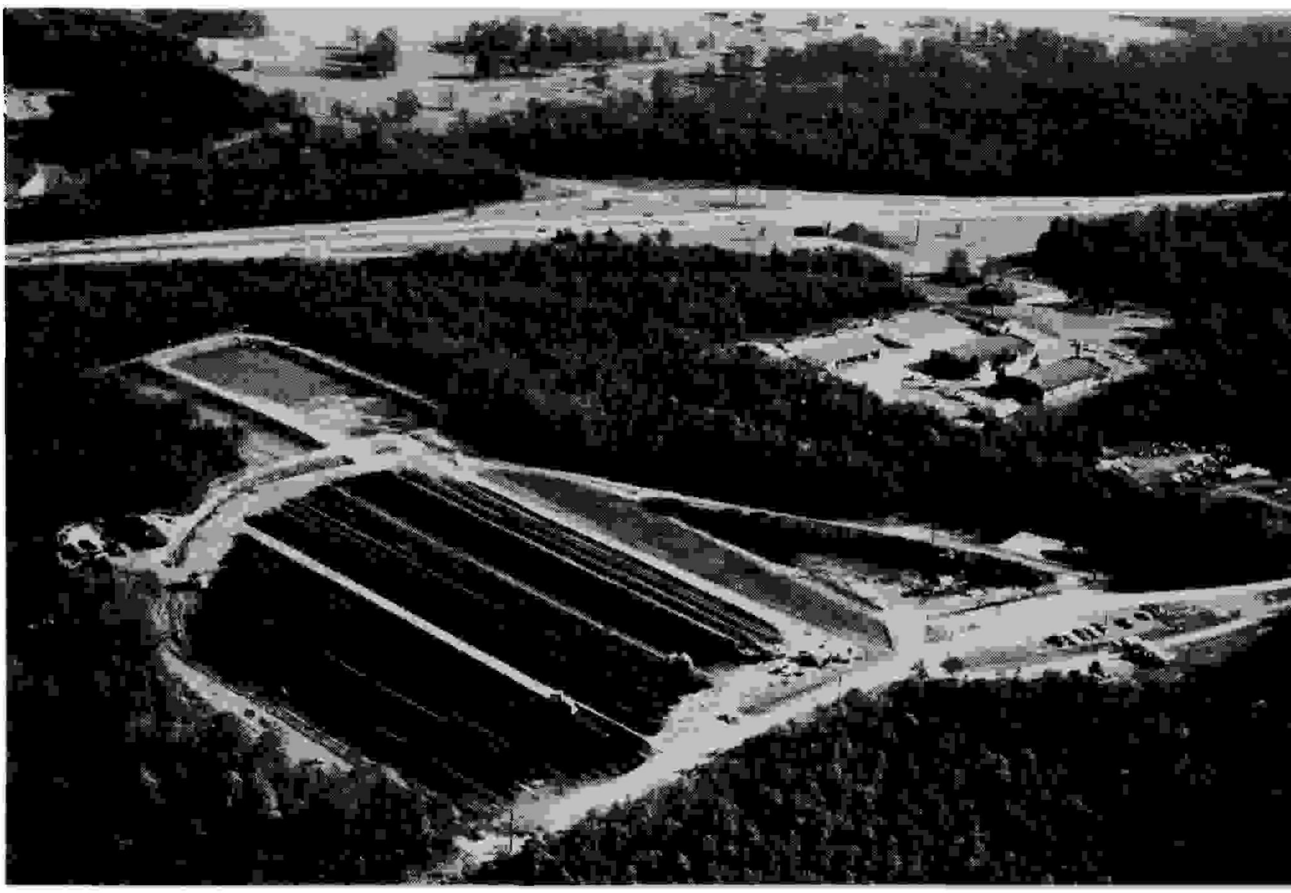

Figure 2: Compost Site.

increasing the porosity for greater air movement and distribution.

3. The windrows are turned for a two week period or longer depending on the efficiency of composting; i.e., achieving temperatures above 50°C. The compost row is then flattened for further drying.

4. Material removed from the windrow is further cured for 30 days. Curing further stabilizes the compost and provides additional time for pathogen destruction. This curing can take place either before of after screening. Screening separates the bulk of the wood chips from the fine material. The wood chips are reused in subsequent composting and generally last through five composting cycles. A system of forced aeration is being tested to accelerate curing.

From April to mid-June 1973, about 200 wet tons of sludge were processed weekly. From mid-June to mid-September sludge delivery increased to 400 wet tons per five-day week. Sludge delivery rose from an average of 400 wet tons per five-day week in the latter part of September to over 930 wet tons on the week of October 8. A large portion of the sludge delivered at that time was raw or undigested. During September, October, and November, odor problems occurred and, because of considerable public protest, operations essentially ceased during December. From January to the present, about 50 wet tons of digested sludge per day have been composted without odor problems. The odor problems were believed to result from: (a) Overloading the site—projected capacity of this site was 100 to 150 wet tons per day; and on October 24, 283 wet tons of raw sludge were delivered; (b) receiving raw instead of digested sludge; (c) possible heavy use of chemicals such as $FeCl_3$ and lime added in the wastewater treatment plant; and (d) climatic conditions including air inversions and stagnation, and wet periods that delayed composting.

The experience of the past year suggests that with digested sludge, present operating procedures could be used satisfactorily in this area. Winter operations required extra effort and longer detention in the windrows. Several modifications seem promising for winter composting and will be

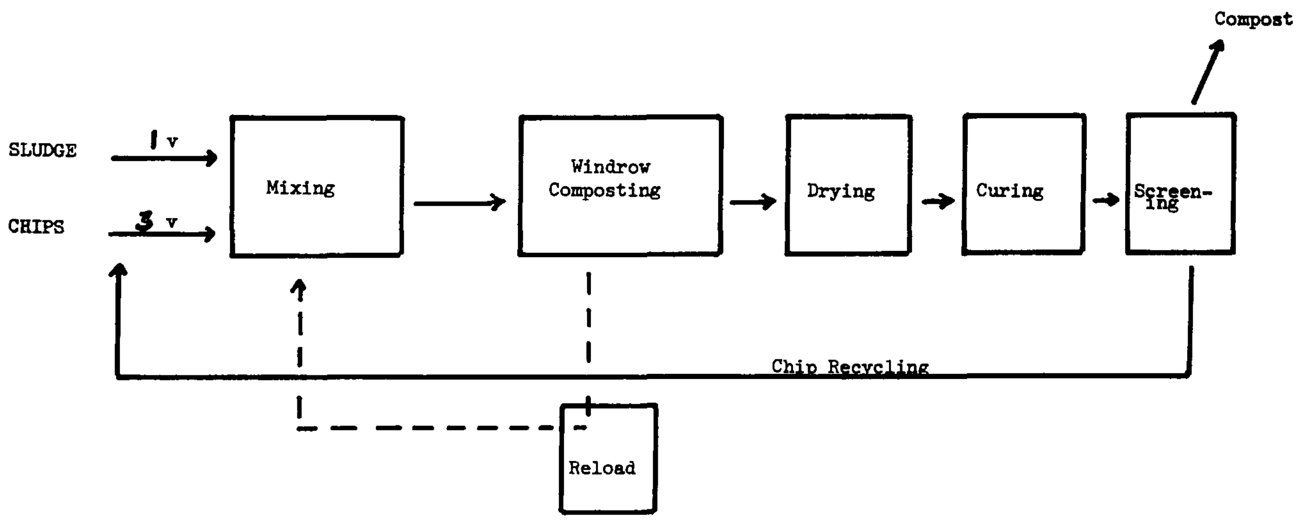

Figure 3: Compost Process.

evaluated this coming winter when additional research is planned.

Desirable modifications and improvements in operations and site design are suggested below.

1. The windrow pad should be paved with concrete to provide a stable pad with better drainage. The present pad's instability is due to: (a) high water table and poor drainage, and (b) tearing up by heavy equipment. Water and sludge are held in depressions which could cause odor problems as well as machinery slippage. Also, the present pad was constructed from locally available crushed stone which is from serpentine rock that contains enough nickel to contaminate the resulting compost. Loose and decomposed stones from the pad are often found in the sieved compost.

2. A partially covered site may be necessary to compost in the winter and during rainy periods. Possibly in a covered or enclosed system, odors, which generally develop during the first six days of processing, may be controlled. This concept needs further investigation.

3. The stockpile areas, chip storage, and curing areas are too small at the present site. Additional space is needed for drying the wet windrows.

4. The wash area should be built so that the sludge washed from trucks would be collected into a septic tank or sewage system, which should be cleaned out periodically.

5. The present access roads are dusty and are difficult to maintain during snowy winter months. These should be improved.

6. If odor-masking facilities are necessary, a better system should be designed. Possibly a pipe-mast system in the direction of the prevailing winds would be more adequate.

Although the present equipment can do an adequate job, the following improvements are desirable.

Composter

1. The composter should be able to build a windrow approximately five to six feet high with a density of 50 pounds per cubic foot.

2. The composter should be able to mix materials well with as few passes as necessary to obtain a good mix.

3. The composter drive system and the wheel drive system should be separate. The wheel drive system should have variable speed control to compensate for changing pad and material conditions. This will reduce wheel slippage and allow for better mixing.

Screen

1. The motors should be dust-proof or a hydraulic system installed.

2. The hopper should be redesigned to be capable of handling full loads from front-end loaders.

3. Transferring of material to the conveyer needs improvement because the conveyer is too narrow and results in too much slippage.

Operations

Two major operational problems have been encountered in the past year: (1) how to compost digested sludge under adverse weather conditions; and (2) how to compost raw sludge without producing odors.

Digested sludge composts slower than raw sludge, particularly during wet, cold periods, possibly because of the lack of sufficient digestible energy material for rapid biological oxidation. Our research shows that adding material, such as chopped hay, straw, or shredded paper, greatly accelerates composting of digested sludge. Thus, adding material to the wood chips to enhance composting in cold, wet periods may be necessary. In the improved process temperatures are increased probably because of reduced air movement and reduced moisture content, resulting in better granulation of the sludge.

Research is being conducted on microbiological, chemical, and mechanical means of preventing odors during composting of raw sludge.

Management

A compost site should be managed by an individual familiar with composting technology and composting equipment. Good coordination is needed between the sewage treatment plant and the composting site. If possible, research and technical assistance should be an integral part of the composting operation. If the research arm is a separate unit, good coordination and relations are absolutely necessary. Facilities, such as space on the pad, that do not interfere with the normal operating procedures must be present for research or development. As technological problems develop (such as odors or reduced composting temperatures), the site manager should be able to communicate effectively with the research personnel. They in turn should be able to respond to the problems immediately.

An efficient compost removal, marketing, or public distribution system needs to be developed that does not interfere with normal operations or traffic at the site. Visitors should not interfere with operations. Essentially, a well-defined organizational structure is necessary which cordinates the activities of site operations, treatment plant operations, research and development, marketing, and public relations.

For greatest efficiency and lowest cost, locating the composting site as an integral component of the wastewater treatment plant would be desirable.

Public Relations

Public relations can often spell the success or failure of a waste treatment project. Requirements in this area will be considered for both the planning and operation stages.

Planning Stage

The planning stage is crucial, and should be initiated well in advance of the project. It must be well-organized and staffed by tactful public-relation individuals. The following are some of the points to be considered:

1. Contact local organizations and explain project—What problems can be encountered? What procedures will be used when problems occur? Types of organizations include:

League of Women Voters
Isaack Walton League
Community citizen groups
Garden clubs

2. Organize a steering committee from local organizations.
3. Provide information to local papers, citizen group papers, etc.
4. Contact political units; i.e., City Council, local politicians, Congressmen, etc. Try to find individuals who have an interest in the program and involve them.

Operation Stage

1. Develop a youth program, such as a beautification and horticultural program in schools and youth organizations. Involve youth in the community improvement and recreational projects.
2. Stimulate adult interest through groups like garden clubs.
3. Provide compost material for community projects.
4. Possibly provide limited amount to local citizens for personal use.
5. Publicize use of compost on public lands instead of other material (peat, humus, top soil) that normally must be purchased. Explain what this represents in savings to the taxpayer.
6. Maintain public relations with community groups and constantly provide information to local and citizen papers. If problems develop, inform the public immediately of your awareness and attempts to solve the problems.

Economics and Costs

Table 1 provides information on costs of composting on a site capable of handling 200 wet tons per day on a seven-day per week basis. The following cost estimates do not include land acquisition, hauling sludge to the site, and compost distribution. We have not attempted to balance these costs with direct benefits (sales of product) or indirect benefits (cleaner environment, improved soil).

In cold, humid climates, part or all of the pad may have to be covered. The cost of composting sewage sludge will also be affected by whether the runoff could be recycled into the sewage system. The

TABLE 1
Estimated Annual Operating Costs for Processing 200 Wet Tons Per Day (20 Percent Solids) of Digested Sludge[a]

Operational Cost

Labor costs, including insurance and taxes (7 men - 40 hrs./wk.)	$90,000
Management and overhead	24,000
Fuel and electricity	14,000
Site maintenance	10,000
Equipment maintenance	10,000
Supplies	14,000
Wood chips	140,000
	$302,000

Equipment		*DIRMI** %	*Annual Capital Cost*
1 Composter	$120,000	34.5	$41,400
1 Composter (backup)	120,000	20.0	24,000
1 Front-end loader large	80,000	34.5	27,600
1 Front-end loader small	40,000	34.5	13,800
Dump truck & pickup	34,000	34.5	11,730
Scale	12,400	21.5	2,666
Mobile office trailer	55,000	24,5	1,225
Irrigation, Deodorizer	10,000	24.5	2,450
Tractor, harrow, sprayer	6,000	24.5	1,470
Screen	50,000	34.5	17,250
Miscellaneous equipment	10,000	24.5	2,450
	$487,400		$146,041

*Depreciation, interest, repairs, maintenance, and insurance.

Construction

Concrete Compost pad (5 acres)	$500,000	13	$65,000
Storage Area	50,000	13	6,500
Runoff and pond	30,000	13	3,900
Roadways	30,000	13	3,900
	$660,000		$85,800

Investment —	Equipment	$487,400
	Construction	660,000
	Total	$1,147,400
Annual Costs —	*Capital Costs*	
	Equipment	$146,041
	Construction	85,800
	Total Capital Costs	$231,841
	Operating Cost	302,000
	Total Annual Costs	$533,841
Cost per ton of wet sludge		$7.31

[a]We thank Dr. Gar Forsht, Economic Research Service, USDA, and Mr. Ronald Albrecht, Maryland Environmental Service, for their assistance in cost estimation.

annual cost in Table 1 for the 200-wet-tons-per-day site is estimated at $7.31 per wet ton or $30.00 per dry ton. Increasing the capacity to handle 600 wet tons per day will reduce the cost to $5.15 per wet ton or $21.12 per dry ton of sludge. Wood chips contribute over $2 per wet ton to the costs, most of which is for chip hauling. A waste product that could be used for bulking and would otherwise cost money to get rid of would reduce these costs.

Municipalities should not view composting of sewage sludge as a potential money maker, but as a means of reducing sludge disposal cost from wastewater treatment plants. Major assets of compost are that it is an aesthetically pleasing, easily handled material that can be used in urban environments without causing odor or nuisance problems.

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RECENT SANITARY DISTRICT HISTORY IN LAND RECLAMATION AND SLUDGE UTILIZATION

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INTRODUCTION

Area Served

The Metropolitan Sanitary District of Greater Chicago, an organization chartered under the statutes of the State of Illinois, serves an 860 square mile area with a population of approximately 5 ½ million persons. The non-domestic waste load, including industrial, commercial, infiltration and storm-water, adds the equivalent of an additional 5 ½ million persons. All of the area served is located within Cook County Illinois and is composed of the city of Chicago as well as approximately 120 other cities and suburbs.

Forms of Sludge

Three major treatment plants handle the daily flow of 1.4 billion gallons. The major treatment process of heated anaerobic digestion, Imhoff digestion followed by sand bed drying, and heat drying of vacuum filtered waste activated sludge, produce approximately 625 dry tons of solids per day.

Heat dried sludge is disposed of thru a contractor who transports the total output of this process to the southern states and Canada for agricultural use. The Imhoff sludge from the sand drying beds is removed to a storage area for additional dewatering and decomposition. Final disposal has been by occasional contract and pickup from the general public. In recent months all of the output of the anaerobic digesters of the major plant, West-Southwest has been sent to Fulton County for storage prior to land application. On a volume basis this amounts to approximately 7000 wet tons per day.

Of the three sludge forms being processed the air dried sludge has the most desirable properties for land utilization. Essential plant nutrient analysis averages 4-6-0.1 for nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) while dry matter content varies from 30 to 70 percent. However, the air dried sludge is much more valuable, on a dry matter basis than are the other sludges, because of the much greater stabilization which it has undergone. One appears to be justified in considering the organic content of the air dried sludge to be essentially humic matter. As such, its importance for rebuilding topsoil would be well appreciated by the agricultural community.

Heat dried sludge has an N-P_2O_5—K_2O analysis of approximately 6-5-0.5 with about a five percent moisture content. However, the valuable components of alkalinity, and humic content are essentially missing because of relatively little biological stabilization prior to the drying operation. Anaerobically digested sludge, on the other hand, has considerable alkalinity, 3-4000 mg/l but the solids content only averages four percent as it comes out of the digesters. Analysis shows the digested sludge to average 6-5-0.5 for N-P_2O_5 and K_2O. Lagooning concentrates solids to eight percent.

Projects to Date in Land Reclamation

Northwestern University Campus

In April of 1968 the Sanitary District, at the request of Northwestern University officials, began a program of applying digested sludge to University owned land. A five acre peninsula had been constructed from dredged sand by the University. On top of the sand an 18 inch clay layer was placed to hold the sand in place and to provide sufficient water holding capabilities for vegetation. A rate of 100 dry tons per acre of digested sludge was applied to the soil by the ridge and furrow method of irrigation. Test wells for water monitoring indicated no detrimental effects due to infiltration. Soil structure and pH were improved to the extent that shrubs and an excellent grass cover could be established and maintained.

Ottawa, Illinois

At a 37 acre site near Ottawa, Illinois, the Libby-Owens-Ford Company disposed of waste silica sand from a glass manufacturing operation. Because of the nature of the sand, the site was bare of vegetative cover so that moderate winds caused severe dust problems. Digested sludge was applied to the site by gated pipe irrigation methods. The initial soil pH of approximately eleven was reduced to near neutral and sufficient organic matter was added to the soil so that a good vegetative cover of grass could be established and maintained.

Hanover Park

The village of Hanover Park, Illinois, located in northwestern Cook County, has a 6 mgd treatment plant serving the residential area. In 1968 an eight acre site was developed for investigating the effects of sludge fertilization on agricultural crops. The site was prepared so that surface and subsurface water could be collected for analysis. Six plots were established and have been planted to field corn during each of the subsequent years. Heavy metal analysis of corn plant tissue and of the grain has been the major research interest. To date, results indicate that corn grown under such conditions does not differ from corn grown under conventional practices except for an increased protein content of the grain.

Calumet Farm

At the Calumet Sewage Treatment Plant a rubbish disposal site of approximately 60 has been reclaimed for agricultural cropping purposes. Surface debris has been removed and sludge applied so that a productive soil has been formed. At the end of the 1973 growing season an accumulated total of 237 dry tons per acre had been accomplished over the five years of sludge application. Application has been done entirely by flood irrigation practices as the fields are essentially level. Field corn and wheat have been the crops grown to date at this site.

Palzo Project

The Shawnee National Forest located near Carbondale, Illinois has considerable acreage of strip mined land within its confines. Generally, the surface water leaving the mined areas has pH values in the 3.0 range. This prevents most forms of biological growth in and along the receiving streams. In addition to the pH problem, a rock problem exists such that use of the lands for cultivated purposes is economically not feasible.

In 1970 The National Forest Service in cooperation with The Sanitary District conducted an application rate study on four test plots. Dry sludge solids were applied at rates of up to 100 tons per acre where the applied material was digested sludge. Various grasses were planted on the plots following sludge application. Companion plots received applications of agricultural limestone and commercial fertilizer.

Only on the plot with the highest application rate of sludge did a substantial grass growth occur. Testing of soil pH indicated that change in the pH was primarily responsible for vegetative growth. The plots receiving limestone tended to have acid leaching through the soil at a later date. This resulted in a reversion of soil pH's and loss of vegetative vigor.

As a result of the pilot plot trials The National Forest Service has prepared a 190 acre site for sludge application. At the present time a contractor is removing sludge from a lagoon at the Calumet Plant site and is transporting it to the application site and will apply it over a period of several years. The Sanitary District has also cooperated with the Forest Service on this larger scale project. Extensive water monitoring is being done on the site to determine the effects of the sludge application and subsequent vegetative establishment..

Arcola Project

For the past several years a private firm has applied lagooned digested sludge to a 900 acre agricultural site at Arcola, Illinois. On occasion, loading rates of 150 dry tons per acre per year have been accomplished under the supervision of the Illinois Environmental Protection Agency. The firm has the responsibility for all phases of the operation, starting with sludge removal from the lagoon. A unit train is used for transportation of sludge to the site with application being done by traveling sprinklers or by moldboard plow incorporation.

Elwood Agronomy Research Center

In conjunction with the University of Illinois, a research center for agronomic studies has been operated at Elwood, Illinois since 1968. A total of 44 plots, each of 10 feet by 50 feet, have been used to study several soil types under sludge application. Plot borders are isolated from surrounding groundwater by plastic sheets with total water drainage being collected for analysis. The facility was designed to provide a means of determining the accumulative concentration changes of plant nutrients, non-essential heavy metals, and organic carbon, along with the change in biological status of soils and water from cropped land irrigated with various rates of digested sludge.

To date, one of the significant research results has been the indication that application of freshly digested sludge can inhibit or prohibit seed germination. However, if the sludge is applied approximately one week prior to planting or if the sludge has been lagooned for some time prior to application, germination will proceed normally. Offensive odors from well digested sludge applications have not been a problem.

The Fulton County Land Reclamation and Utilization Site

Land Acquisition

In the fall of 1970 the Sanitary District made an initial purchase of land in Fulton County, Illinois, approximately two hundred miles away from the sludge treatment facilities. The land was a combination of place land and strip mined land. Of the strip mined land, some areas had been partially leveled so that grazing operations could be undertaken.

Fulton County, Illinois is one of three counties in Illinois which traditionally lead the state in coal production. Over the past several years, an average of 1650 acres per year has been stripped in the county. Since approximately 40,000 acres of such strip mined land already exist in the county, it was obvious to concerned county officials that something must be done to counteract this erosion of the economic base of the county. As a result, Fulton County officials and District officials got together.

Steering Committee

At an early date a steering Committee was formed which had the responsibility of a multidisciplined advisory group to the District. Represented on the committee are University research personnel, State Water Survey personnel, University Extension Service, Federal and State Soil Conservation personnel, elected county officials, representatives of various local communities, citizen organizations and District personnel. Their task was to review the various proposals offered by the District and to suggest modifications for maximizing benefits of the proposals to all parties.

Transportation System

A transportation system was developed for moving digested sludge directly from the digesters and hauling it by barge down the Illinois River. At the downstream end a dock was constructed for handling the barges and associated pumps. The sludge is removed from the barges with portable pumps which discharge into the suction line of booster pumps. From this point the material is pumped through an underground 20 inch pipeline a distance of 10.8 miles to holding basins.

Holding Basins

The holding basins were constructed near the center of the planned utilization facility. Four individual cells comprise the total storage capacity of approximately 8.1 million cubic yards. Each basin was lined with a two foot thick compacted clay liner to prevent seepage and one basin is ringed with a number of wells for purposes of collecting ground water to detect seepage from the basins.

The basins receive sludge every day of the year barring exceptionally heavy ice or flood conditions on the river, and mechanical breakdowns. Two functions are served by the basins: to accumulate sludge without the need of immediate application, and to separate liquid from solids. Separation permits application of a sludge with a solids concentration which can be different from the sludge being input to the basins.

Distribution System

A conventional dredge is used to remove sludge from the holding basins. It has a cutter head which can reach depths in excess of 30 feet and is moved in an oscillatory manner when removing settled solids. The dredge discharges into a floating pontoon line which conveys the sludge to several large holding tanks.

From the holding tanks the sludge is fed to two pumps in series which have a collective capability of delivering 1200 gpm at 80 psi. The output of the distribution pumps is conveyed through a surface layed, ten inch, steel line out to the fields for application. Each of the presently installed eight distribution lines services an area of approximately 250 acres.

Within the field, portable, eight inch, aluminum irrigation piping conveys the sludge to the various areas. Traveling sprinklers do the major amount of sludge application and they are connected to the aluminum line with a five inch diameter 660 foot long hose. In some instances a tandem disk equipped with a distribution manifold is connected to the five inch hose for incorporating sludge as it is applied. Either application method can cover a maximum area of approximately ten acres with a single settling of the aluminum pipe. Sludge is applied during the growing months of May through October with the distribution pipeline being flushed with water and then drained for winter periods.

Site Preparation

Prior to sludge application each field is leveled by construction equipment to maximum slopes of approximately six percent. Berms are placed around the field so that all surface water runoff is directed to adjacent retention basins for temporary storage and analysis prior to release to the water course. Retention basin capacity is designed to receive the 100 year frequency storm, which for the Fulton County area amounts to a bit over five inches of water. Rocks and other debris are removed from the field during site preparation. Those areas that were scarified and which will not become part of the productive field are seeded to permanent grass for erosion control.

Environmental Protection System

The system is designed to operate in a fail safe manner. Complete surface water collection is accomplished by directing application field runoff to retention basins. The water is then analyzed prior to release to show that it meets State water quality standards. In addition, several small streams that run through the property are monitored at points where they enter and leave District Property. The State Water Survey, IEPA and the County Health Department also monitor some of these streams as well as several other locations within the property.

Numerous shallow wells have been located throughout the property for purposes of supplying ground water for monitoring purposes. Shallow wells for ground water monitoring purposes surround the holding basin that was put into operation first. Extensive use of grassed waterways reduces the sediment load that leaves the fields during heavy rains. The waterways also provide for additional utilization of nutrients prior to entry of the runoff into retention basins.

Cropping Program

The basic aim of the Sanitary District is to be able to apply as much sludge to a particular location as the environmental limitations will permit. In this regard, the agricultural cropping program is a vital component. Information indicates that somewhat less than half of the applied nitrogen in this system ends up in the soil and is thus available for plants. The remaining portion evolves to the atmosphere as gaseous nitrogen. To the present date, nitrogen has been the primary parameter by which loading rates were determined. Of all conventional agricultural crops, field corn has been the crop that used the greatest amount of nitrogen and presented the fewest management difficulties during its production.

The Sanitary District procures the services of local farming organizations through competitive bidding on crop production contracts. The contractor is essentially responsible for all phases of the crop from "bag to bin". During the growth of the crop the District supplies the required fertility to the crop by sludge application. Marketing of the crop has been done by contract through local commercial grain dealers.

Production records indicate that when sludge is applied to strip mined land, corn yield has been increased by approximately a factor of four when compared to those strip mined fields which received no sludge. Because strip mined soils have no organic matter to speak of, they have relatively little ability to contain adequate amounts of soil moisture. Therefore, it appears important that sludge be applied in the liquid form until soil organic matter is built up to a sufficient level.

Many good agricultural soils range from three to five percent in organic matter. An application of 100 dry tons per acre of the District's air dried sludge would change the soil organic matter content by approximately one percent. At this rate the entire daily solids output of the District, 625 dry tons, could only improve six acres per day by an organic matter change of one percent. On an annual basis this approximately equals the acreage which is strip mined in one county of one state, Fulton County, Illinois. Conservation of a valuable commodity must receive greater attention.

Research Studies

The District's Research and Development Department is studying quite a number of factors connected with the long range changes that might result from sludge application in an agricultural setting. In addition to the above mentioned parameters that are being tested, lakes on the site are periodically sampled for biological specimens ranging from microorganisms to fish. Grain and plant tissue analysis is conducted on the crops being grown.

In cooperation with the University of Illinois School of Veterinary Medicine a grazing study is underway which involves approximately 100 head of beef brood cows. The cattle consume forages produced entirely from sludge fertilized lands. During the summer the cows directly graze an irrigated crop while during the winter they graze stubble fields or are in dry lot. The cows and their calves are being examined for parasitic changes, heavy metal concentration changes and changes due to disease producing organisms.

A number of small plots have been established on strip mined soil near the holding basins. Studies on these plots involve crop response to sludge fertilization, soil response to sludge fertilization, and the effects, on soil water, of sludge migration down through the soil profile. Because of variable environmental conditions it is sometimes unreliable to extrapolate data collected from plots in a different locale.

Multiple Use Facilities

Throughout the early development and implementation of the reclamation site, considerable emphasis has been placed on multiple utilization. Various integral parts of the site have been developed for public uses such as boating, camping, fishing and hiking while other parts have been devoted to improving the habitat for wildlife. Several hundred acres of land, within which are sludge recycle fields, has been leased to the county government. They in turn are responsible for managing the area for public utilization. The State of Illinois Department of Conservation is cooperating in the wildlife habitat improvement and stocking of the strip mined lakes for fishing. Efforts continue on the project for reestablishment of a native population of giant Canada geese.

Future Developments

Application Rates

At present, the Illinois Environmental Protection Agency has approved application rates on the Fulton County site of 75 dry tons per acre per year for strip mined land and 25 dry tons per acre per year for place land. These rates pertain to liquid application wherein the solids content might reach a maximum of eight percent. Over a period of five years the application rates are reduced to a steady-state rate of 20 dry tons.

Infiltration rates for the clay soils of the area restrict the amount of water that can be applied over and above a normal annual rainfall of approximately 35 inches. It appears that an average year would result in approximately four acre inches of sludge being applied to the soils. This factor would limit maximum dry matter application to approximately 36 dry tons per acre per year if eight percent solids are in the irrigant. Therefore, it appears that in the near future, the District will be strongly considering application of a sludge which can be handled as a dry material. Several major benefits of such a move would be that annual application limits could be achieved in a single application, organic matter could be built up in the soils at a much more desirable rate, and that sludge could be incorporated shortly after application to result in much less nutrient and particulate loss from the field due to erosion.

The concentration of heavy metals in the soil is a factor that can be controlled to any desired degree. One can monitor the soil for metal concentration and the crop for toxicity indications. If, and when, crop toxicity is encountered one can relieve the metal concentration in the soil by tilling more deeply. The normal plow layer is considered to be eight inches. It is presently possible to till to a depth of approximately 36 inches with existing equipment. More than a four-fold reduction in concentration would result from such action. Fears that there are no practical responses to too high of a metal concentration in the soil appear to be unfounded.

Reclamation and Strip Mining

Some of the land that the District is now leveling and reclaiming has been laying in an unproductive condition for a great number of years. The land has become overgrown with low quality trees and vast amounts of soil has been conveyed to nearby streams over the years. In considering the total cost to society for such practices, it does not appear reasonable that such a time span need exist between strip mining and reclamation.

Recent State of Illinois laws have required current strip mined spoils to be leveled to slopes of no greater than 15 percent. However, this practice can only be viewed as a partial solution to the problem. Long slopes of only several percent on bare soil cause serious erosion problems. This condition is coupled with the fact that soils devoid of organic matter take an exceedingly long time to establish adequate vegetative cover. Before vegetation protects the soil from erosion, ditches are formed which concentrate water flow and cause still more serious erosion. The process is a never ending cycle as soil must be moved to correct the ditch problem and the process is repeated.

The missing key to the reclamation of these soils is organic matter. The incorporation of sludge into freshly leveled mine spoil immediately after stripping appears to present the most desirable benefits for sludge utilization and land reclamation. Nowhere in agriculture are such quantities of organic matter available at a cost which would be comparable to that of sludge.

SLUDGE MANAGEMENT IN ALLEGHENY COUNTY

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I am delighted to have the opportunity to participate in a Conference which brings together the interest and expertise of individuals so deeply concerned with the subject of sludge and to share with you, information on existing activities and potential practices dealing with this timely topic in Allegheny County.

We are pleased to relate that as a conservation and resource recovery concept, the recycling of municipal sludges to the land is a practice of long standing in Allegheny County. While this method of disposal is apparently serving the County in an environmentally acceptable manner, there is a growing awareness that the advent of advanced wastewater treatment processes and the need to attain higher degrees of pollutant removal will create as much as a 50 to 80 percent increase in sludge quantities. In addition, these sludges will contain chemicals introduced as part of the wastewater treatment process that may alter the character of the waste material.

It would be appropriate to provide you with some pertinent background information on our County. Allegheny County embraces an area of about 745 sq. miles with a population of about 1.6 million, residing in 129 separate municipalities. Of that population, approximately 97 percent is served by sewerage systems with the remaining three percent still utilizing private on-lot systems, such as septic tanks. There are about 45 sewage treatment plants with design flows ranging from 0.1 mgd to the Alcosan facility with a design flow of 150 mgd. The number of plants with design flows under 0.1 mgd approaches 100. Those facilities serving small industries, commercial facilities, and institutions are slowly being abandoned as a result of the construction of new and enlarged municipal plants and the extension of new and existing interceptors.

In terms of sludge generation, it is estimated that between 150 and 175 tons of dry solids are produced daily by all the plants in the County. Of that amount, the Allegheny County Sanitary Authority (Alcosan) facility produces on the average about 113 tons. Since another member of this panel will describe sludge management at Alcosan, I shall not attempt to do so except to relate that incineration is the final reduction process.

Although an average of 75 percent of the sludge generated in the County is processed by combustion, most of the balance is digested anaerobically with a small amount digested aerobically. The latter method of processing has found acceptance with consultants in several of the new plants, especially those designed under 3 mgd. An example of that type of facility is one which serves the greater Pittsburgh Airport and four surrounding communities and utilizes the contact stabilization process with aerobic digestion of sludge for present low flows averaging 0.80 mgd. As the volumes approach the design capacity of 2.5 mgd. then *high lime treatment of sludge with thickening and vacuum filtering* may be considered as an alternative to an aerobic digestion. While stabilizing the sludge by adding lime of a pH of about 12 is not a new treatment concept the possibility of its use here is comparatively recent. It is well understood that most soils and crops are benefited by lime treatment; therefore, agricultural applications of lime stabilized sludges may be thought of as environmentally feasible. R. B. Dean and J. E. Smith, Jr. of the EPA, in their paper titled the "Properties of Sludge" indicate that lime inactivates most heavy metals by precipitation and the use of high limed sludge as a soil amendment would pose only minimal risks. In this regard, the only treatment facility in the County which could contain heavy metals in its sludge to any appreciable degree would be the Alcosan facility. Practically all the other plants treat a fairly homogenous domestic waste.

You may ask about the Commonwealth of Pennsylvania's role in the area of sludge management and how their enforcement posture affects the County. Under Department of Environmental Resources Rules and Regulations Article I, Land Resources, Chapter 75 "Solid Waste Management, Paragraph 75.116" sewage solids, liquids, and hazardous waste, Section (B) reads "Sewage sludge shall be digested properly and dried to approximately 80 percent moisture contents by weight. Septic system cleanings shall not be allowed except as approved by the Department." To our knowledge, sludges being disposed in sanitary landfills meet that criterion because until only recently, there were no landfills approved for that purpose. Within the past six months however, one of the seven permitted landfills in the County constructed a leachate treatment facility which employs a lime-acid-aeration process. The operator of another fill has connected his leachate flows to the sanitary sewer of a treatment facility. Two other sanitary landfills located in strip mined areas are approved even though treatment facilities do not exist. In spite of a lack of treatment, these fills are being monitored by means of wells to assure that pollutants are not reaching surface waters.

Now you may feel compelled to question how we can boast about recycling of sludge when sanitary landfills are becoming readily available for disposal. Our reaction is that sanitary landfills would have to be necessarily considered as disposal sites of last resort. The continued application of sludges on agricultural land meeting the landfill criteria is expected and encouraged. However, it is most obvious that state and County controls for sludge disposal on farm land or home gardens or wherever are much more difficult to enforce since there are many more sites to inspect. If there is a breakdown in sludge treatment efficiency or a lack of complete treatment in accordance with State standards then the potential public health implications become magnified. We are all too familiar with the gastroenteric effects of pathogenic bacteria and viruses attributed to human wastes.

How is the Pennsylvania Department of Environmental Resources coping with this problem? In cooperation with the Allegheny County Health Department, the State now requires all new applicants and also those treatment facilities being upgraded or expanded to provide the following type of information:

1. Type of sludge and physical characteristics.
2. Groundwater module phase 1 or water quality management module 5 (with required maps).
3. General Site information.
   (a) Location of private water supplies in the area.
   (b) Surface water drainage characteristics.
   (c) Assurance that the site is compatible with the requirements of local ordinances.
4. Method of operations.
   (a) Quantity of sludge to be deposited.
   (b) Frequency of spreading.
   (c) Method of spreading (how and what type of equipment).
   (d) Method of working into soil.
   (e) Provisions for adverse weather handling and storage.

While this regulatory approach appears to be operating well for the treatment facilities mentioned previously and classified as new and upgraded, an enforcement gap exists with those facilities at the secondary level of treatment which are not yet under orders to improve their process. However, within the short term future, the Department of Environmental Resources and the County will be able to account for practically all large scale disposal of sludge on land.

You generally have a blueprint of existing experiences with sludge in this County. What of the future? What new concepts or perspectives lie ahead? Given the impetus provided by the Environmental Protection Agency's R. J. Schneider in his paper at last summer's Conference on "Recycling Municipal Sludges and Effluents on Land", the County is preparing to undertake a few demonstration projects which will enable either the County and/or operating authorities in the County to develop cost effective programs with alternatives for recycling of potential sewage pollutants through products of agriculture and silva culture as stated in Title II of the amended Federal Water Pollution Control Act of 1972.

The County, through the services of a consultant, has applied to the Environmental Protection Agency for a grant to initiate a project titled "Restoration of Strip Mine Lands Using Municipal Treatment Plant Residues and Fly Ash". Since our area is blessed with an abundance of plant residues, fly ash, and strip mine areas which constitute our major mode of solid waste disposal, we feel a project of this kind, while not necessarily unique in itself, represents a potential technical benchmark for the County.

The project entails the following:

OBJECTIVE

To conduct a feasibility study for renovation of strip mine land in one Township of the County by either mixing municipal sludges with ambient soils and spoils or a combination of municipal sludges and fly ash. Unlike existing projects, it is proposed to combine a need for disposing the *maximum* quantity of residue with the need to restore strip mine lands for a community resource.

Following a demonstration of the feasibility of the concept, a field demonstration will be initiated embodying all the precepts outlined in the feasibility study (Phase II). Following the successful completion of the demonstration, a full scale operation will be considered (Phase III).

SPECIFIC OBJECTIVES

(1) Inventory of existing acid mine drainage.
(2) Sampling and characterization of residues.
(3) Feasibility of application of residues.
(4) Socio-economic benefits that will be realized.
(5) Assurances that State and County pollution abatement programs will aid in restoration of the waterways.
(6) Method description, development of demonstration project, and full scale operation.
(7) Preliminary engineering to determine capital, operating costs and benefits that will accrue to the project.

Some of the highlights of the project include:

Surface and sub-surface water quality and quantity data will be obtained to determine existing conditions, for monitoring requirements, for site modifications, for engineering requirements, and for operational requirements.

Physical and chemical analyses of the soils and spoils will be obtained for design of the greenhouse and site cropping studies.

"Greenhouse" studies will be conducted using site soil, sludge(s) and fly ash with various proposed grasses and forest crops to be determined by the ultimate use of the site(s).

Replicate plots at the proposed site will be utilized to verify the ranges of sludge applications and growth phenomena.

One management alternative for handling sludge during the winter months is to compost sludges for subsequent cover of the municipal sludges being applied to the uncropped lands to minimize odors.

At the present time, the application is being held in abeyance until July 1, of this year for resubmission to the Federal Government. The State has given the County a green light on the project providing certain conditions are met such as the submittal of an erosion and control plan.

Another innovative research project in which the County intends to participate is the processing of dewatered undigested sludge produced at the Pine Creek water pollution control facility now under construction adjacent to the County's first solid waste transfer station. The consulting engineer for the McCandless Township Sanitary Authority plans to design treatment units arranged so that any of the several modifications of the activated sludge process may be employed.

Since the facilities will be constructed in four stages, beginning with 3 mgd flow capacity units, the consultant will propose that the filter cake produced from thickened and dewatering undigested sewage sludge solids, conditioned with ferric chloride and sufficient lime to maintain a pH of 12, free from odors and pathogenic organisms, be transported by tank truck to the transfer station for mixing with solid wastes and subsequent disposal in a landfill, as a temporary expedient. As treatment plant capacity increases then future provisions for another method of sludge processing such as incineration will be evaluated.

The actual logistics for services and details of this unique arrangement will be developed within the next year. The state at this stage has given this proposal an experimental approval pending submission of all required and supporting engineering data.

It would be most relevant to add that the current energy crisis will provide us with the opportunity to examine the advantages of burning combustible materials from the transfer station with the sludge. Of course, this change in operation at the station would require extensive physical additions and modifications to the facility for separation and shredding. Another possibility, depending upon the success of our strip mine project, would entail the combining of the organics from the station with the sludge to increase the viability of that project. It would be worthwhile to mention that the County anticipates the construction of two additional transfer stations as part of our solid waste management program.

The last system which the County may consider at the site would be the use of a high performance fluid bed reactor. This system would utilize solid waste as a fuel to dispose of all the sludge in a pollution free manner. The system requires the installation of blowers, magnetic separators, air classifiers, shredders, scrubbers, and a thermal energy recovery system. Naturally, the residue emanating from the operation would have to be disposed of in a landfill unless the market value for ferrous materials, glass, aluminum, and other non-magnetic metals warrants reclamation.

In addition to the potential systems which have been described, the County will encourage and promote the use of the available sludge processing capacity at various plant locations throughout the County. If the County is able to designate, with the cooperation of about a dozen authorities, certain treatment facilities where operators of small facilities may transport their liquid sludges for ultimate processing, we may then be better assured that indiscriminate dumping of waste material is reduced and the environment, as a result, enhanced.

In conclusion, Allegheny County is on the threshold of an era of significant experimentation and demonstration, not only in sludge management but also in solid waste management areas which are so closely intertwined. We are hopeful that our efforts and accomplishments will not only benefit the County but also serve as a model for similar environmental activities throughout the Country.

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TRENCH INCORPORATION OF SEWAGE SLUDGE*

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ABSTRACT

Entrenchment seems a feasible method for simultaneously disposing of sewage sludges and improving marginal agricultural land, particularly for dewatered (20 percent solids) raw-limed sludge. The primary problem will be to avoid pollution of groundwater with nitrate-nitrogen, as demonstrated in test with sewage sludge (5 and 20 percent solids) placed in 60-cm (two foot) wide trenches of different depths and spacings. For dewatered sludge, application rates were 800 and 1200 Mt/ha (350 and 500 tons/acre) *dry solids*, respectively, in trenches 60 cm wide x 60 cm deep x 60 cm apart and 60 cm wide x 120 cm deep x 120 cm apart.

Entrenchment prevented contamination of surface water, buried pathogens permitting their demise during sludge decomposition, promoted slow nitrogen release, and favored denitrification.

Nineteen months after sludge entrenchment, fecal coliform and salmonella bacteria had not been detected in soil more than a few centimeters from the entrenched sludge. No downward movement of heavy metals had been detected, and metal uptake by crops had been moderate. Nitrate movement had occurred, causing increased levels in underdrained water. Groundwater in monitoring wells had not shown increases in any pollutants except chloride that might have come from the sludge.

Recommendations are given for running a sludge trenching operation.

INTRODUCTION

The lack of environmentally acceptable procedures for sewage sludge disposal seriously hinders adequate treatment of municipal wastewater. The better the wastewater treatment, the greater the amount of sewage sludge generated and requiring disposal.

Although all wastewater treatment plants have a serious sludge disposal problem, the 1.14 million cu meter (300 million gallon) per day Blue Plains Plant, which serves much of the Metropolitan Washington, D.C. Area, has a particularly acute one. Since 1972 Blue Plains has been required to reduce the BOD of the secondary effluent discharged into the Potomac River. They had planned to reduce this BOD by treating the effluent with either $FeCl_3$ or alum, but they have had no environmentally and politically acceptable alternative for disposing of the resulting greatly increased quantities of sludge—much of which would be undigested.

Early in 1972, the District of Columbia Government (DC), the Environmental Protection Agency (EPA), the Maryland Environmental Service (MES), and other State, county, and local agencies and groups launched a cooperative effort with the Agricultural Research Service (ARS) of the United States Department of Agriculture, to find an environmentally acceptable procedure for sewage sludge disposal.

*Based in part on a study by the Agricultural Research Service of the U.S. Department of Agriculture in cooperation with the Maryland Environmental Service of the Maryland Department of Natural Resources, the District of Columbia Bureau of Wastewater Treatment, and the Office of Research and Monitoring of the U.S. Environmental Protection Agency.

A comprehensive research-demonstration study was undertaken for evaluating the trenching of raw and digested sewage sludge to improve agriculturally marginal soils and simultaneously provide an economically feasible, environmentally sound, and politically acceptable alternative for sewage sludge disposal. These studies included: (1) Field testing on large-scale to develop feasible all-weather procedures for hauling and incorporating sewage sludge in the soil in trenches; (2) Characterizing the proposed treatment site by investigating its hydrologic properties as well as the biological and chemical properties of the surface and underground waters and the soils; (3) Testing a drainage control system for the site; (4) Establishing a program to monitor the movement, form, persistence, etc., of sludge nitrogen, heavy metals (zinc, copper, cadmium, nickel, etc.) and pathogens in soil, underground and surface waters, and plants growing on the site; and (5) Supporting laboratory and greenhouse studies.

Field Entrenchment of Sludge

Site Preparation

We selected a 30-hectare (75-acre) experimental site which seemed to offer excellent possibilities for improvement with sludge, for monitoring, and for drainage control. It was readily accessible to heavy equipment, distant from residential development, and had very sandy soils, which made it an excellent site to test whether pollutants from entrenched sludge would move into the groundwater.

Approximately 50 soil borings were made to map the water table and underlying impervious clay layers. Many of these borings were converted into monitoring wells. All of the wells in the immediate plot area were cased, grouted, and sampled before sludge was incorporated.

Based on the map of the water table and underlying impervious soil layers, diversion drains (surface and subsurface) were installed at several locations (Figure 1). Test ditches showed that the soil was so

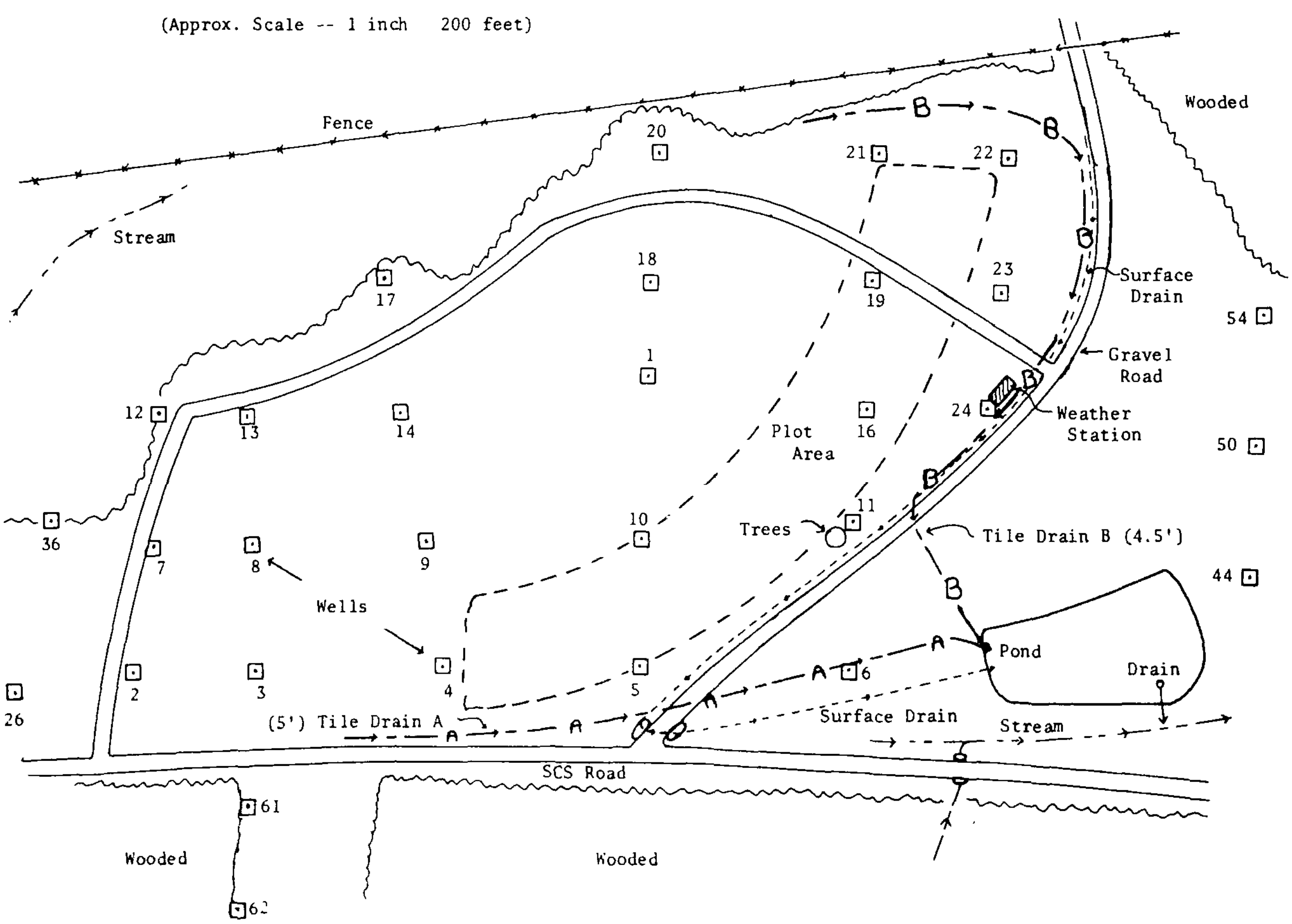

Figure 1: Partial Site Map (Sludge Entrenched in the Plot Area).

sandy and wet that open ditches for conventional tile laying would collapse. A special trenching machine with shields behind the trenching wheel (Table 1) was used to lay a 12.5-cm (five inch) corrugated plastic drain tube which was slotted and screened. A laser beam guidance system was used to accurately place the tile line on a 0.1 and 0.2 percent grade. A drainage catchment pond with a 3,785 cu meter (one million gallon) capacity was constructed down slope. This pond could hold about two months' normal drainage from the site.

Sludge Entrenchment

The engineering firm of Whitman, Requardt, and Associates worked with ARS to establish and test trenching procedures for incorporating digested and raw-limed sewage sludge into soil. Test treatments used are listed in Table 2. Standard equipment items were rented (Table 1).

TABLE 1
Heavy Equipment Used at Beltsville in the Trenching Pilot Study[a]

	Site Preparation - Pond Construction and Drainage	
1	Speicher VT600 -	6 wheel drive trencher with laser beam automatic grade control
1	Caterpillar - D-6	
1	Caterpillar - D-7	
1	International 0.7 M^3 (7/8 yd^3) backhoe	
	Sludge Entrenchment	
1	Cleveland JS-36 Trencher	with tiltable and traversible 60 cm (24-inch) wide trencher wheel
	Caterpillar - 977 loader with 3.4 M^3 (4-1/2 yd^3) bucket	
1	Caterpillar crawler loader with 1.9 M^3 (2-1/2 yd^3) bucket	
1	Caterpillar - D-8	
1	Caterpillar - D-7 - with winch	
Numerous-	10-wheel, 12 M^3 (16 yd^3) dump trucks	
1	23 M^3 (6,000-gallon) pneumatically operated tank truck	
1	Caterpillar - motor grader	
1	50-cm (20-inch) farm disk	

[a] Mention of trade names, contractors, consultants, and commercial products is for the convenience of our readers and does not imply endorsement or recommendation for use by the United States Department of Agriculture.

TABLE 2
Sludge Entrenchment Data

Treatment a & b	Trench Depth cm. foot	Spacing[a] between trenches planned, ft.	actual ft.	Sludge Type[b]	Actual Solids %	Rate[c] dry solids MT/ha	tons/a	Plot Sizes a & b each ha	acre
I	60 (2)	2	3.0	Digested	27.6	830	(360)	6.3	(0.75)
II	120 (4)	4	4.9	Digested	27.6	1150	(500)	0.1	(0.25)
II	60 (2)	2	2.1	Raw-Limed	18.5	740	(320)	0.05	(0.12)
IV	120 (4)	6	8.7	Raw-Limed	9.3	130	(55)	0.05	(0.12)
V a	60 (2)	2	3.0	None	NA[d]		(0)		
b	120 (4)	4	4.9	None	NA		(0)		

[a] Assuming trench width of two feet exactly.
[b] Digested and liquid raw-limed from Blue Plains and dewatered raw-limed from Fairfax plants.
[c] Assuming 0.85 wet tons/cu. yd. and ten percent trench overfill.
[d] Not applicable.

The prime goal was simulation of full-scale trenching of dewatered sludge at the rates generated at Blue Plains. Twelve-cubic meter (16-cubic yard) dump trucks were used for hauling. The initial plan was to discharge the sludge onto the ground near the open trenches so that front-end loaders could gather up the sludge and place it in the trenches. This plan proved unsatisfactory because the jelly-like sludge was very difficult to scoop up with the loader buckets. Both the trucks and front-end loaders tracked sludge all over the soil surface, making it very wet and slippery and difficult for the trencher to operate. Furthermore, the trucks tracked the sludge onto the site roads and the highway.

Temporary storage pits were established into which the sludge was dumped and from which the loaders obtained the sludge. This was a considerable improvement. The pits, approximately 2 meters deep x 4 meters wide x 12 meters long (6.5 x 13 x 26 feet), were pushed into the soil with a bulldozer. Sludge still fouled the pit entrances and the soil surface near the trenches, so pit entrances had to be continually scraped with a bulldozer. Occasionally, to keep the trencher from slipping, the sludge impregnated soils in the trench area were also scraped. Pits were closed as they became impassable and/or too far from trenches.

Trenches, dug along the contour, were filled with sludge by using front-end loaders (Figure 2). The loaders buckets held more sludge than a segment of 60- x 60-cm trench the length of the bucket could contain. To guide the filling considerable care and skill of operators as well as a field assistant standing by the trenches were needed. Usually, trenches were ten percent overfilled. As the trencher dug a new trench, properly spaced from the first, it simultaneously covered the previous trench with the diggings (Figure 3).

Because the trencher lacked grouser bars on the track pads it slipped in wet weather. The trencher could only be operated in one direction because the operator's seat was located on one side, which caused visibility problems. The trencher operator had to see the previous trench and needed guidance from a field assistant to keep the trenches straight, properly spaced, and at the proper depth. The trencher operated at approximately six meters (25 feet) per minute in dry weather when digging 60-cm (two-foot) deep trenches. When trenches were 120 cm (four feet) deep, the walls of the very sandy soil often collapsed. Lateral force from the adjacent previously filled and covered trenches aggravated the situation. An occasional increase in the spacing between trenches helped prevent collapse.

On a dry surface the rubber-tired front-end loader was very mobile, fast, and efficient in filling the trenches, but it often got stuck in wet weather. Although it could usually work itself free, in so doing it tore up the soil surface. Under wet conditions, crawler-loader was better but slower and less mobile than the rubber-tired loader, and considerably disrupted the soil surface. The wet, disrupted soil surface required leveling and scraping with a bulldozer and/or several days' drying before trenching could be continued.

The dump trucks were not ideal for hauling sludge. They leaked sludge liquid onto the highway, would not unload completely, and often became stuck at the site. Sludge adhered to the truck tires, mud flaps, and chassis and dropped onto the soil surface and highway.

The on-site gravel roads were barely adequate in wet weather. They had to be graded continuously and gravel added to maintain a crown and allow drying.

Even with all the difficulties involved with learning a new operation and the less than ideal equipment, sludge was trucked to the site and incorporated in trenches at the expected rate of sludge production at Blue Plains. For example, 450 filter-cake tons (20 percent solids) of digested sludge were incorporated into 120 cm (four foot) deep trenches (plot IIa) in six hours, using only the 977 rubber-tired loader. This was equivalent to a rate of 600 filter-cake tons per eight-hour day (calculated from Table 2). Approximately 2,000 filter-cake tons of sludge were incorporated into plots Ia and Ib(0.6 hectares—1.5 acres) under very wet conditions in 27 hours, not counting time off during rain. Both front-end loaders were used. This again was equivalent to a rate of 600 filter-cake tons per eight-hour day.

With the standard equipment used, trenching sludge in the rain was not possible. Modifications of procedures have been recommended to improve the cleanliness and desirability of the operation and make it nearly possible to operate during all kinds of weather. These modifications include installation of grouser bars on the trencher, use of cement trucks for hauling sludge and discharging it directly into trenches in dry weather or into special bulldozer-pulled trailers in wet weather, and unloading the trailers into the trenches with a Moyno pump. Clean sludge-handling equipment and prompt filling and covering of raw-limed and digested sludge, dewatered within the past 24 to 48 hours, is necessary to prevent malodor problems.

Figure 2: Trencher Digging a Trench and Loader Filling It with Sludge.

Figure 3: Trencher Digging a New Trench with the Diggings Covering Simultaneously the Previous Trench That Had Been Filled with Sludge.

Liquid Sludge Incorporation

The procedure used to incorporate liquid sludge into trenches was unsatisfactory. Because of logistical problems and the desire not to backfill immediately, all trenches were dug before sludge incorporation. Approximately a 2.5-meter (eight-foot) spacing between trenches was necessary to prevent collapse in the sandy soil (Table 2). Liquid sludge was successfully discharged into the trenches pneumatically from a large tank truck. Dewatering occurred very slowly and additional sludge could not be added. The 120-cm (four-foot) deep trenches could only be one-third to one-half filled or sludge would run out during backfilling with spoil.

Costs

Projected costs for trenching sewage sludge have been taken from a report by Resource Management Associates, Inc. (See Reference List) prepared for the Maryland Environmental Service. These costs are summarized briefly in Table 3. Capital costs are mainly for site development and equipment. Most site development funds are for on-site roads on two 40-hectare (100-acre) sites. Capital funds are also included for drainage and water containment at the two sites.

The equipment costs are for purchasing 14 pieces of equipment such as crawler dozers and loaders, trenchers, sludge pump trailers, a motor grader, etc., which would be transported between each site as necessary. The capital costs do not include purchase or rental of land or equipment resale value at the end of two years.

Operating costs are mostly for amortization of capital costs (six percent) over a two-year period, equipment operations, and labor. Labor funds were projected for 13 employees. The operating costs do not include sludge transportation. A total cost of $10.17 per ton of filter-cake sludge was estimated for trenching at a rate of 400 filter-cake tons per day. This cost is competitive with that of other sludge disposal methods.

TABLE 3
Estimated Costs[a,b] for Trenching

Costs for two-year operation at 400 filter-cake tons per day	
CAPITAL	
Site development (two separate 100 acre-sites)	$576,000
Loader hopper at treatment plant	20,000
Equipment	492,000
OPERATING (annual)	
Capital amortization and interest (6%)	$593,000
Equipment operation	110,000
Labor	233,000
Miscellaneous	5,000
Costs per filter-cake 400 filter-cake tons per day level	
CAPITAL	$ 3.72
OPERATING	6.45
Total	$10.17

[a]From costs estimated by Resource Management Associates, Inc., for the Maryland Environmental Services
[b]Costs do not include land acquisition, transportation, or any resale value of equipment at the end of 2 years

Environmental Effects

Environmental effects of high rate sludge application to land were studied in groundwater observation wells, in underground and surface drainage water, in soil below and around entrenched sludge, within entrenched sludge, and on crops.

Nineteen months after entrenchment, no salmonella and fecal coliform bacteria, no nitrogen, and no metals were detected in groundwater wells that came through soil from the sludge. Measurements of drainage water and soil under trenches, however, suggested that nitrate pollution would probably become a problem as sludge weathers (dries out) and becomes more aerobic. Fecal coliform and salmonella bacteria were not detected more than a few centimeters below the trenches and the organisms were only detected in surface drainage water at the time of sludge incorporation due to sludge spillage on the soil surface. Laboratory studies suggest that viruses can move in soils, but not likely far or fast enough to constitute a hazard. Studies on virus movement through soil are continuing. Heavy metals had not been detected moving down into soil out of entrenched sludge.

Sludges weather (dry out) in soils after entrenchment. Root penetration speeds the process (Figure 4). The sludge is changed from a malodorous, dense, anaerobic, water-shedding material to an aerobic porous peatlike consistency in which nitrification is facilitated and denitrification inhibited.

Considerable nitrate-nitrogen apparently is lost by denitrification, (the bacteriological conversion of nitrate to nitrogen gas, which occurs under anaerobic conditions with a carbon energy source required). Nevertheless, nitrate levels were increased in the soil under the trenches and in drainage water. Drainage and impoundment of infiltrating rain water will likely be necessary. This

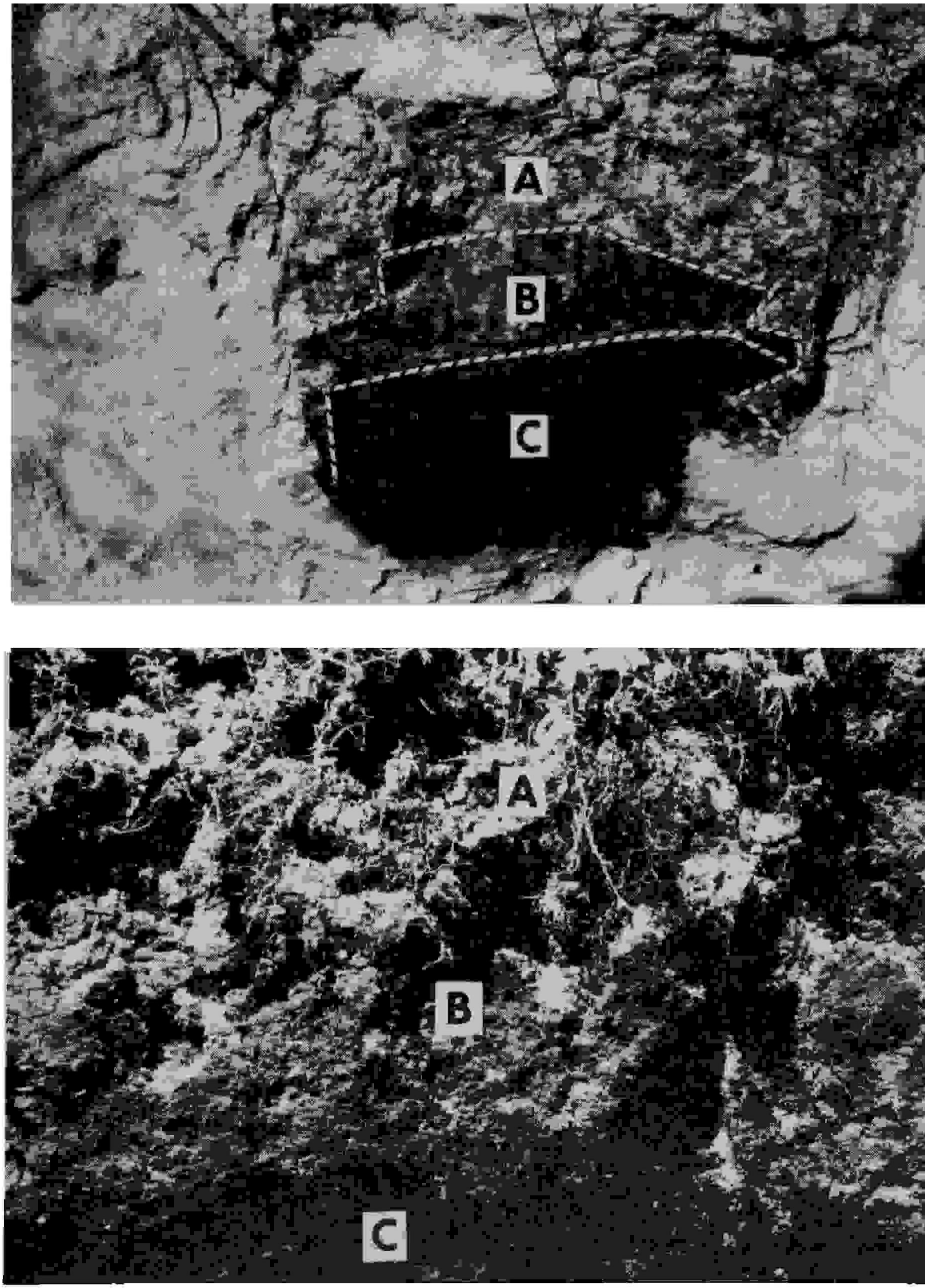

Figure 4. Cross-Sectional Excavation of Entrenched Digested Sludge 17 Months (Oct. 17, 1973) Showing Degree of Weathering. Zone A = Weathered, Densely Rooted, Peatlike, Aerobic. Zone B = Weathered, Sparsely Rooted, Moist, Peatlike, Aerobic. Zone C = Unweathered, Anaerobic.

impounded water, if contaminated with excessive levels of nitrate, could be applied as irrigation water on surrounding land, where crops would remove the nitrate.

Metal availability to plants apparently increased as sludge weathered. DTPA-TEA-chelate-extractable metals (an index of plant available metals) and plant uptake showed this trend. Metals, however, were apparently less available in the most weathered sludges as compared to intermediately weathered sludges in a greenhouse study. Overall uptake of metals by crops growing on the trench study plots has been moderate.

Digested sludges (60-cm trenches) were about one-half weathered to peatlike consistency 19 months after entrenchment, and raw-limed sludges were approximately one-fifth peatlike. Studies will continue on the fate of pathogens, nitrogen, and metals as weathering continues.

Growth of crops like fescue, alfalfa, rye, and trees in the sandy infertile soils in our studies seems to have benefited from entrenched sludge. Detailed data and discussions of environmental effects may be found in our research reports on trenching (See Reference List).

RECOMMENDATIONS

General

Trenching seems to be a suitable procedure for high rate disposal and application of sewage sludge to land. Trenching would be an appropriate system to use when low-rate (fertilizer-rate) surface application of sludge is not feasible, e.g., with raw sludge. Properly used, the procedure seems environmentally safe and compatible with use of the land for some agricultural purposes. Trenching would not be appropriate in prime agricultural land because of subsoil being brought to the surface and the amount of trace elements applied. Because we have only been able to study the effects of trenching for a short time under limited conditions, any system using the trenching procedure now for land application of sludge should include careful monitoring.

Desirable Site Characteristics

A good site should have: A substratum suitable for establishment of a drain system, a good location for a holding pond, good vehicular access, a rural location, slopes less than 15 percent where sludge is to be applied, and soil of marginal agricultural value—first choice would be a heavy soil underlain with an impermeable stratum. Sites with sandy soils, while less desirable, may still be suitable. If fissured rocks are present, they should be at least three meters (ten feet) below the surface.

Survey

To determine its suitability, the potential trench application site must be studied carefully to characterize: (a) The surface and subsoil; (b) the topography; (c) the distance to fissured rock; (d) location of any hard, impervious layers; (e) location of permanent and perched water tables; (f) the direction and flow of underground waters; (g) potential for underground drainage; (h) areas for suitable waterholding ponds; and (i) adequate access for heavy trucks and other field equipment.

Site Drainage

A drainage network should be installed with the average depth 120 to 150 cm (four-five feet). Pond storage capacity should be adequate to hold drained water for approximately two months. If contaminated, the water could be applied on surrounding land for purification by crop utilization and percolation through soil. Drainage and surface water control should be under the guidance of any agency like the Soil Conservation Service.

Trenches

Trenches should be dug on the contour at the time the sludge is available. The trenches should then be covered the same day that they are filled. A trenching machine should have cleated tracks and a rear-mounted digging wheel that is movable from side to side and tiltable. For maximum benefit and decreased nitrate hazard, limed sludges should be placed in trenches no more than 75 cm (30 inches) deep and 60 cm (24 inches) wide and 60 to 75 cm (24 to 30 inches) apart edge to edge. Sludges placed in narrow trenches (less than 60 cm (24 inches) wide) would result in greater soil sludge contact and more aerobic conditions. Narrow trenches would probably favor more rapid nitrification with less denitrification, and consequently increase the danger of nitrate pollution of groundwater.

Sludges

Sludges should be entrenched at high disposal rates when use of low fertilizer application rates (25 to 55 dry MT per hectare annually or 10 to 25 dry tons per acre annually) mixed into the soil surface to a depth of 15 cm (six inches) of soil is not possible. The low-rate application of sludge to the soil surface compared with high-rate application in trenches would yield full agricultural benefit of sludge nutrients and avoid the potential movement of nitrate and excessive metal accumulation in soils.

Sludges to be entrenched should first be limed and dewatered. The pH of the sludge at time of dewatering should exceed 11.5 to reduce survival of pathogens and to lower the potential for metal accumulation by crops. The metal content of sludges should be as low as possible to further decrease potential for excessive uptake of metals by crops.

Raw sludges should not be applied to land except in trenches because of the potential pathogen hazard and odor problem associated with surface incorporation. Metals content is less and apparently risk of nitrate movement is less from a given volume of raw than of digested entrenched sludge.

Hauling and Filling

A sealed cement-type truck is recommended for hauling the sludge from the wastewater treatment plant to the trench incorporation site. This truck could also then be driven directly to the trenches when the soil is dry and capable of bearing the load. The sludge could then be unloaded from the cement truck via its own extended discharge chute. In wet weather, the cement truck could discharge the sludge into a trailer outfitted with a Moyno pump. A bulldozer could then pull the high flotation trailer near the trench so that the sludge could be unloaded via the pump into the trenches.

Preparation for Seeding

To prevent erosion and permit soil stabilization, the trenched area should be left ridged until weather is suitable for leveling and seeding. When leveling freshly filled and covered trenches, a bulldozer or some other suitable tracked vehicle should be used at right angles to the trenches. Deep cross-ripping of the entrenched sludge is unnecessary in sandy soil. Its possible benefit should be determined in clay soil. Based on soil tests and the crop to be grown, fertilizer and lime should be applied and worked into the soil surface. The lime and fertilizer requirement could be reduced by surface application of approximately 23 to 45 dry MT per hectare (10 to 20 dry tons per acre) of digested sludge.

Crops

Crops should be limited to grass the first year. Initially the trenches can be leveled and cultivated only at right angles. If row crops are subsequently grown, they should be planted on the contour to prevent excessive erosion. Because of uncertainty on availability of metals to crops grown on trenched soils, crops grown should not be used in the food chain unless monitored to determine their safety.

Monitoring

Since monitoring is extremely important and so little is known about the long-term effects of trenching on the environment, it should be the responsibility of a qualified trained individual responsible to a governmental institution, such as the State Department of Health. Monitoring should begin before sludge is applied and continue for at least five years after application. Monitoring for a large-scale trenching operation might include determinations as suggested below. A smaller operation would require less monitoring.

Background samples should be taken from strategically located groundwater wells a month or two before sludge is applied. These wells should be located both inside and on the downflow side of the underground water coming from the entrenchment site. Background analyses should include some of the following determinations: fecal coliforms, PCB's, chlorinated hydrocarbon pesticides, alkalinity, organic nitrogen, nitrate nitrogen, ammonium nitrogen, chlorides, pH, solids, BOB, COD, phosphate, calcium, sulfate, manganese, zinc, cadmium, nickel, copper, lead, mercury, potassium, magnesium, sodium, and specific conductivity. If techniques are available the water might also be analyzed for viruses. A similar analysis for the background parameters should be made 6 to 12 months after sludge incorporation and then yearly thereafter for at least five years. Well water should be sampled more often (monthly to tri-monthly) depending upon the well location, and analyzed for fecal coliform, chloride, ammonium nitrogen, and nitrate nitrogen.

At least two complete sets of background analyses, preferably at three-month intervals, should be made of residential wells located within a one- to two-mile radius of the area of sludge entrenchment.

Composite samples should be collected and analyzed monthly from streams draining the area, from major subsurface collector lines draining the area, and from ponds holding drainage water. This sampling should begin two months before sludge application, continue at monthly intervals thereafter, until one year after all sludge has been incorporated, and then periodically for two to four years. Analyses of these samples might include fecal coliforms, pH, dissolved oxygen, BOD and COD, chloride, ammonium, nitrate, total nitrogen, and phosphorus.

Representative soil samples should be collected to the depth of proposed entrenchment in the area to be treated and analyzed prior to sludge incorporation for cation exchange capacity, texture, and pH. It also may be useful to know the soil levels of potassium, phosphorus, soluble salts, chlorides and metals like zinc, copper, cadmium, nickel, lead and mercury.

Before sludges are entrenched, they should be continuously monitored during each day for pH at the treatment plant. At the time of dewatering the pH should exceed 11.5. A composite sludge sample should be carefully assembled biweekly from daily composited samples and analyzed for chloride, fecal coliforms, salmonellae, and metals like zinc, copper, nickel, cadmium, lead, and mercury. Less frequent analyses for viruses, total and ammonium nitrogen, phosphate, potassium, $CaCO_3$ equivalent and percent volatile solids may also be helpful.

Crops grown on the area to receive sludge should be sampled and analyzed semiannually for at least five years for uptake of zinc, copper, cadmium, nickel, lead, and mercury. The same crops grown on nearly similar soils should be analyzed as a control.

Research

Considerable additional research is needed on sludge handling and incorporation in soil and in trenches that will result in minimum hazard to the environment and maximum benefit from sludge disposal and land reclamation. A portion of the funds for the trenching operations should be allocated for research. Research personnel should cooperate to determine the environmental effects of even larger scale trenching operations than previously studied. Other research would include studies on: (a) Placement of raw and digested sludge with and without lime and other chemical treatment in trenches in different types of soils, on which the surface and underground water, the entrenched sludge, and the soil surrounding the sludges would be carefully studied for movement and survival of pathogens; movement of nitrogen, the metals (zinc, copper, nickel and cadmium), chlorides, and COD; pH; weathering; and degree of plant root penetration; (b) movement of viruses through soils both in the field and in the laboratory; and (c) availability of heavy metals to crops. Routine composite samples of different sludges and their effluents at treatment plants should be taken and analyzed for metals biweekly. These analyses can be used to identify more clearly the effects of chemical treatment and at what point in treatment different sludge components are separated out. The metal measurements in the sludges, along with metal measurements of wastewater at suspected discharge points, can be useful to identify sources of metal pollution, i.e., from point-sources, general industrial and domestic sources, and/or street runoff. These determinations should also be very useful for reasonably predicting the potential usefulness of the tested sludges on land.

Summation

These recommendations on trenching procedures are based on data from limited experiments over a short time. We believe, however, that this research shows that dewatered sludge can be trenched safely by following our present recommendations. The most likely difficulty is that excessive nitrogen from the sludge might reach underground water. This nitrogen problem can be minimized by underdraining the entrenchment site and retaining the drained water for irrigation of surrounding land.

Implementation of Land Use-Disposal Sludge

Special approaches are needed to implement not only a sludge trenching operation, but any land use disposal system for sludge. Because of political, environmental, and energy limitations, the primary method for sludge disposal is rapidly shifting to land use. This a *radical change* from considering that sludge should be merely incinerated, landfilled, or dumped in the ocean.

Land use for disposal of sludge requires a new set of specialized skills. Wastewater treatment authorities must now learn all about the limits of sludge application to land, including presence in sludge of pathogens, heavy metals, salts, nitrogen, and phosphorus. They also must be aware that soil type, its acidity, and the crops can limit sludge use on land. They may discover that sludge cannot be used on land until its heavy metal content has been reduced, because once these metals are added to soils they remain and may later become hazardous. They soon will discover that sludge application to soil is limited in poor weather and when crops are growing. They will discover that regulations for sludge use on farmland will be restrictive and conservative with different rules than for placing sludge in trenches. They finally will discover, quickly, that not nearly enough is known about long-term effects of sludge on soils, water, crops, and the food chain. Although they will be tempted to dismiss land use as a means of sludge disposal, land use of sludge will soon be one of the only available methods of land disposal.

Because of weather limitations and all the other uncertainties about land use of sludge, every land use system must have one or more back-up sludge use or disposal alternatives. For example, a trenching operation should have a landfill, incineration, land spreading, or some other back-up or combination of these back-up alternatives.

The problem areas listed in Table 4 will likely be encountered in any sludge use disposal operation. To avoid these problems we must be aware of the limits of sludge application to land and seek adequate consultation on establishing the proposed land use system. With trenching, changing some of the recommendations can be beneficial, while other changes e.g., ignoring the weather, using trenches too narrow or too deep, providing no drainage, using leaking trucks, failure to cover sludge promptly—may be disasterous and lead to a court order to cease operations. Finally, the public must be involved from the beginning and aware of the problems with free discussion of possible solutions in arranging for sludge disposal.

TABLE 4
Problem Areas in Trying to Implement a Sludge Land Use - Trenching Operation

(1) Budget
(2) Coordination of treatment plant personnel with land use personnel to avoid establishment of a treatment process yielding a sludge that cannot be used on land
(3) Availability of proper equipment, e.g., sealed hauling
(4) Untrained and/or inexperienced supervisors and operators
(5) Monitoring
(6) Uncertainty of procedures and needs to avoid adverse effects of sludge on the environment
(7) Alternative back-up sludge disposal and/or use procedures
(8) Contracts with firms for sludge use disposal must specify procedures so that proper careful operation is encouraged
(9) Early and continued public involvement

I hope that we can find needed answers for implementing land use systems for sludge disposal as soon as possible. Some answers, however, will come slowly. Meanwhile, land use operations for sludge disposal must be clean, prompt, backed up with disposal alternatives to use during periods of rain or poor sludge quality, and have the active support of the public.

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OCEAN DISPOSAL EXPERIENCES IN PHILADELPHIA

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INTRODUCTION

Ocean disposal of digested sludge in Philadelphia is a very simple "unit" operation. First, the sludge is digested, using standard-rate anaerobic digesters, and pumped to an on-site lagoon for thickening. This step results in thickening of the sludge from seven percent to about 12.5 percent. From the lagoon, the sludge is pumped to the barge via a ten inch Ellicott Dredge. The barge has a capacity of two million gallons and is equipped with an 18 inch, hydraulically operated, bottom dump valve. The barge is towed downriver and out to a prescribed disposal area where the sludge is discharged at approximately 30,000 gallons per minute over a six mile course. No known harmful effects have occurred as a result of this operation.

Except for one "catch," the story might end at this point with a few additional comments on the economic benefits and operational improvements for the system. That "catch" is called the Marine Protection, Research, and Sanctuaries Act of 1972 (The Act). This Act is the first comprehensive Federal waste disposal control regulation and the discussion that follows will focus on its consequences, both good and bad.

Philadelphia's sludge disposal experiences may be divided into three parts: 1) our experiences prior to the passage of the Act, 2) the Act itself and the effects of its passage on ocean disposal, and 3) the implications of information being developed as a result of the Act's requirements. Hopefully, the discussion will illustrate the need for integrating laws and regulations with sound sludge management concepts.

Choosing and Continuing Ocean Disposal

Three wastewater treatment plants in Philadelphia serve an area of over 360 square miles. The Northeast Plant is now an intermediate-type activated sludge facility while the Southeast and Southwest Plants use primary treatment. The combined capacity is 450 MGD and all of the sludge produced is anaerobically digested and barged to sea. In order to meet more stringent discharge standards, the City is now in the design stage of a $300 million plant expansion program that will result in full secondary treatment at all plants.

Ocean disposal of sludge began in 1961 when it became apparent that, due to growth in the drainage area, available lagoon space would not be sufficient. The decision to begin use of the ocean followed a survey of disposal alternatives which found ocean disposal to be the most economic and practical method. Since 1961, Philadelphia has barged approximately 960 million gallons of sludge to the ocean.

The site chosen in 1961 and used until May, 1973, is a rectangular area (one mile by two miles) located 13 miles off Cape Henlopen, Delaware. The site was selected by considering favorable ocean currents (dilution), depth of water (60 ft.), and the marginal value of shellfishing in the area.

In early 1970, the environmental soundness of our ocean disposal program began to come under review and criticism. Because of the great concern expressed by citizens, various agencies, and government groups, the City contracted with the Franklin Institute Research Laboratories (FIRL) and Jefferson Medical College, both located in Philadelphia, to take samples of the waters and sediments at the disposal site and determine if any harmful effects had occurred.

The FIRL study focused on an area within a six mile radius of the center of the disposal site. Monthly cruises were made to examine the water column, sediments, and biota. The study was completed in February, 1972.

Dissolved oxygen levels in the water were near saturation. Coliform bacteria were found in the trail of a discharging barge, as would be expected. Positive counts existed, however, only while the plume could be seen, a period of about two hours.

Examination of the sediments showed clean sand, gravel, and pebbles. Tests for heavy metals in sediments showed levels in the disposal area to be insignificantly different from contiguous areas of the ocean. Nowhere was there evidence of a sludge blanket.

The diversity of species was high and the animals present appeared healthy. Scuba and TV examination of the bottom revealed normal conditions for the New Jersey coastal region.

The conclusion reached by FIRL was that over ten years of discharging sludge had done little or no perceptible damage to that area of the ocean. While this study has been criticized as being incomplete or inconclusive, the fact remains that a year long study by competent and reputable organizations was unable to detect *any* significant effects.

Recent Regulations and Their Effects

In October, 1972, the United States enacted the Marine Protection, Research, and Sanctuaries Act. The law established regulations and criteria, to be implemented by a permit system, for all forms of waste discharge (except pipeline) to the ocean. The permit system took effect on an interim basis on April 23, 1973, pending development of final criteria. The final criteria were promulgated on October 15, 1973, and the Act went into effect in final form on February 13, 1974.

A detailed discussion of the implementing criteria of the Act is beyond the scope of this paper but a brief treatment of the now final regulations is pertinent. Basically, the criteria contain categories of potentially hazardous materials which are regulated according to concentration definitions. For example, under title "Other Prohibited Materials" are organohalogen compounds, mercury compounds, cadmium compounds, and petroleum products. A dumper must show that his waste contains these materials in less than trace concentrations, as defined in the Act, before a permit can be issued.

Another title by which dumpers are regulated is "Material Requiring Special Care" which lists a wide range of materials that must meet the requirements of a Limiting Permissable Concentration (LPC). The LPC is based upon the results of bioassay testing, an application factor (.01), and definitions of a mixing zone and a release zone. Other requirements of the permit structure include site monitoring, extensive waste analysis, research into alternatives to ocean dumping, and public hearings.

The first direct effect of the permit system on Philadelphia was the movement of the disposal site from 13 miles to 50 miles off the coast. Our permit, issued first on April 23, 1973, required that the new (50 mile) site be in operation by May 8, just two weeks after issuance. The reasons for the move are still unknown but the effect has been a barging cost increase of 175 percent, possible adverse interaction with a nearby acid waste site, and continued opposition from coastal areas.

Another immediate effect was a greatly expanded analysis program due to a requirement for analyzing some 40 parameters on each barge leaving our treatment plants. This program is still in effect at a cost of $40,000 per year for outside laboratory services plus almost 20 percent of our own laboratory man-hours. The program has shown that Philadelphia's sludge meets all requirements, except mercury and cadmium in the "solid phase." Procedures for Hg and Cd, the two most critical parameters, are still in draft form, but indications are that the sludge will exceed the criteria for these metals. This question will be discussed further in a later section.

The permit also required extensive monitoring of the new disposal location. A $250,000 (per year) contract is now being processed to do the monitoring work. Monitoring should begin in August of this year.

The Act makes provision for research into alternatives when a dumper exceeds the criteria. This has led to several comprehensive reports and studies that explore the viability of various alternatives.

On February 13, 1974, due to passage of the final criteria, the City received another interim ocean dumping permit. The requirements of this permit are similar to those mentioned above with the exception of a requirement for an extensive industrial source control program. The program is intended to determine the sources, relative contributions, and controllability of heavy metal sources within the City's drainage area.

Control of Ocean Use

As indicated by the requirements outlined above, a tremendous amount of information has been generated as a result of the Act's passage. In this light, Philadelphia has been very active in reviewing its position on sludge disposal and how regulations such as the Marine Protection Act will ultimately affect the environment. To date, all of the data developed and reviewed leads to the conclusion that controlled, well-managed, ocean disposal is the best sludge disposal method presently available to Philadelphia. Further, it appears that the Act, as it stands now, is overly aggressive in protection of the ocean while not taking into account similar potential hazards of the various alternatives to ocean use. There is a lesson in environmental management to be learned from this situation. Realizing that the discussion of this point may be academic with regard to the Marine Act, the comments that follow may help in considerations of the many disposal options being presented at this conference.

At present, analysis shows that Philadelphia's digested sludge exceeds the criteria of the Act for only two elements, mercury and cadmium in the "solid phase." Two possibilities for checking appear immediately in (1) the analysis and (2) the criteria.

Analysis for many of the materials listed in the Act, including Hg and Cd, had not been routinely performed on sludge until the permit system took effect. Problems have arisen as to confirmation of the resulting data. For example, our laboratory performed the prescribed mercury test for six months under our first permit. The results varied considerably, from 33.6 mg/l to 0.2 mg/l, using the same procedure so that when our new permit was being considered, the sludge could not be adequately compared to the criteria. During this period, we conducted a round-robin confirmation of the data using three analytical methods and five laboratories and found that mercury concentrations were ~ 1.0 mg/l (total).

Even with confirmed data, comparison to the criteria could not be made since the criteria gave concentrations in liquid *and* solid phases. Is sludge a two-phase substance? This depends entirely on the method specified for preparing the samples, and none were available. Recently, a draft form of a new procedure for Hg and Cd was developed by the Regional EPA. This method, by definition, makes the sludge exceed the criteria for Hg and Cd in the solid phase. Should sludge be considered as a liquid, the sludge would exceed the criteria by 1 ppm for cadmium.

There are many such draft procedures from the various EPA regions and yet the law is being implemented on a national basis. It would seem that the law should not precede valid analytical procedures by which the law is implemented.

The wording of the Act is unclear as to what is intended by the distinction between solid and liquid phases when all other substances are limited by the bioassay test. The criteria state that mercury concentrations *in the barge* must be less than 0.75 mg/kg in the solid phase and 1.5 mg/kg in the liquid phase. Philadelphia's discharge rates and bioassay results are well within the criteria but we may be forced to abandon the ocean by concentration values that have already met the toxicity limitations. No consideration seems to be given for dilution which drastically reduces the effective concentration of the waste. Since toxicity is directly proportional to concentration, i.e., availability, limiting discharge by such low concentration values of the waste before dumping seems inappropriate.

Interaction of wastes in a disposal area is another key question. Mentioned earlier, one result of our move to the 50 mile disposal site was a possible interaction with a nearby acid waste site. Recent EPA survey cruises in the area have reported some metal increases in the sediments. While these findings have not been statistically validated, they do point to the possibility of adverse interaction. One hypothesis is that, because the acid waste contains $FeCl_2$, it is causing flocculation and some deposition of sludge solids in the area.

The interaction of two wastes may produce effects at the site totally different from the effects of the materials considered individually making comparison of individual wastes to the criteria meaningless. It may be that grouping of compatible waste discharges is needed to avoid hazardous interactions or, on the other hand, to promote any beneficial effects.

The questions raised regarding the validity of the criteria, if nothing else, show very definitely that much more study is needed towards developing proper ocean management schemes. The Marine Protection Act has accomplished a great deal to this end. We should be investigating maximum loading rates for specific areas. We should be investigating sludge dispersion characteristics in the ocean. We should be carefully monitoring all disposal operations and establishing complete baselines. We should be investigating movement of hazardous materials in the food chain. But we should *not* eliminate the ocean as a disposal alternative before these questions have been adequately answered. In the same way some materials *could* have an adverse effect, eliminating ocean disposal *could* result in the loss of the best possible choice, as the next section will point out.

Alternatives to Ocean Disposal

If disposal of digested sludge is potentially harmful to the ocean, then the same potential exists for other methods like land disposal or incineration. Digested sludge, by its very nature, contains materials that are potentially harmful to the environment if improperly managed. Investigation of the alternatives is not a problem but how to then evaluate the relative impacts of the alternatives has not been clearly established. It is implicit in the passage of the Marine Act that these benefit/damage relationships are known for the ocean but this is insufficient without the same consideration for other disposal means. Further, once the acceptable means of distributing pollutants are established for other segments of the environment, a comprehensive study of the relative value of each segment must be made. Only after this is accomplished can municipalities make design decisions on the best means of ultimate disposal.

The reports and efforts resulting from our permit requirements for research into alternatives warrant discussion at this point to complete the sludge disposal picture for Philadelphia.

There are three basic choices for ultimate disposal of sludge solids. In a report entitled "Report on the Management of By-Product Solids from Water Pollution Control Plants" by our consultants, Greeley and Hansen, the alternatives available to Philadelphia were evaluated on the basis of economics, practicality and environmental concerns.

Economically, all alternatives to ocean disposal were shown to be much more costly to the City. The present cost to the City for ocean disposal (including the recent 175 percent increase) is approximately $17.00 per dry ton of raw sludge. The average cost of the nine disposal alternatives considered was $50.00 per dry ton, an increase of 194 percent. The incineration alternate is estimated to cost on the order of $62.00 per dry ton, a 265 percent increase. Ocean disposal is by-far the most economically attractive disposal method.

The practicality of each alternate was considered by first estimating the implementation times. The study estimates from 7.5 to 12.5 years for implementation of a land spreading operation and from 5.0 to 7.5 years for incineration. It is also pointed out that both may include operational problems. For example, large areas of available land do not exist in the highly populated Northeastern United States. This means that long distance transportation methods are needed which would increase operating difficulties, adverse public reaction, energy consumption and costs.

To give an idea of the land requirements, a recent EPA Policy Statement (draft form) has set up guidelines that fix sludge application rates on agricultural soils. The rate is based on the cation exchange capacity (CEC) of the receiving soil and the zinc equivalent concentration (A.D.A.S., England), in the sludge to be applied. Using analyses of Zn, Cu, and Ni in Philadelphia's sludge and a CEC of 25 meq/100 g-soil (maximum expected in Northeastern U.S.), it would require approximately 2000 acres of new land every year for Philadelphia to dispose of its annual sludge production. Thus, by the year 2000, we would have applied sludge to some 52,000 acres of land. It can be shown that the equivalent loading rate on the land area under our present ocean disposal site is approximately *two dry tons per acre per year.* The EPA Policy Statement would allow loading on the land, with no dilution, of *54 dry tons per acre per year.* Other sections of the Policy leave some question as to whether we would be allowed to apply sludge at all to agricultural land but that discussion must wait for another time.

Also, land spreading may not be done in winter months due to runoff problems and would require large storage facilities. Composting is expected to have problems due to cold weather reducing pile temperatures although the extent of these weather effects is not yet known. Incineration processes require stack gas scrubbing to meet air pollution standards and will require extensive maintenance. Of all the alternatives, ocean disposal was shown to have the least operating problems.

The environmental evaluation showed similar potential hazards are associated with all disposal methods. The potential for heavy metal introduction into the food chain exists for both ocean and land disposal. Clams and other filter feeders could ingest the metals and thus be available for harvesting and ultimately human consumption. In a similar manner, crops grown on sludge enriched soil could be ingested by livestock and also be available for human consumption.

Microorganisms associated with sludge pose threats whether introduced directly to ocean waters or indirectly through percolation to ground waters. Air pollution problems are unique to incineration processes since operation of air scrubber equipment has been insufficient to date. Incineration is also a high energy consumer, as is land spreading, when compared to barging to sea.

The report states that both sea disposal and land disposal have the advantage of supplying nutrients to nutrient deficient areas. The study also points out however, that ocean disposal has the advantage of diluting potentially hazardous materials that land disposal does not, while land disposal does provide somewhat better control.

Overall, ocear disposal did not appear more hazardous to the environment than the other methods considered and if aesthetics and public reactions are included, it appears as the best choice again.

Another result of our ocean permit is the investigation of source control of hazardous materials such as metals. Philadelphia's Industrial Waste Unit is now conducting an extensive survey of area industries to identify controllable sources. Data generated to date indicates that few industries discharge significant quantities of problem heavy metals and even fewer are controllable through pretreatment. That is, even if these sources could reduce their metal concentrations, it appears that the total heavy metal movement in the drainage area would not be changed appreciably. Indications are, therefore, that a high "background" level exists in urban areas that is controllable only through lifestyle changes.

SUMMARY

Philadelphia's recent experience with ocean disposal has led into almost every area of sludge management and its related problems. Implementation of the Marine Protection Act has pointed out that regulation should not result in *over*-control to the point of creating more or equally severe problems in other areas. Further, the ways in which these problems might appear has been discussed to illustrate that management should be the main objective of environmental regulation and not prohibition.

The discussion has pointed out that a major benefit of regulation is the incentive to fill the gaps in "state-of-the-art" knowledge in all areas of sludge disposal. This conference and its proceedings can make a very signficiant contribution to this effort.

SLUDGE DISPOSAL BY INCINERATION AT ALCOSAN

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In recent years, research and design engineers seem to have neglected the difficult problems of sludge handling and disposal in favor of the more glamorous problems associated with the liquid portion of wastewater treatment. The liquid portion has not proved as exasperating to sanitary engineers as has the disposal of the semi-solid residue of wastewater treatment, the sewage sludge. What to do with the solids from constantly escalating treatment procedures is rapidly becoming a major problem to those of us responsible for operating a modern wastewater treatment plant. Not only is solid disposal a major problem, it is without a doubt, the most costly of all the processes. Pittsburgh is no exception.

In the mid-1940's when "Alcosan," the Allegheny County Sanitary Authority was being designed, the Authority's engineers, Metcalf & Eddy of Boston, recommended that Pittsburgh incinerate its sludge. To talk incineration in the mid-1940's was not a problem, but to do it today, it is like discussing Judge Sirica with the Watergate defendents. Nobody likes them. No one likes incineration, find some other method of disposal and locate it someplace else,—especially "someplace else." This was true in Pittsburgh, it is true in Chicago, and it is true in most other cities in the United States. Pittsburgh accepted the challenge, now complicated by increasing volumes of sludge from both domestic and industrial sources, reduced land availability and now reduced public tolerance of air and water pollution. Pittsburgh elected to incinerate and in doing so, eliminated its sludge disposal problems. Before I go into sludge disposal, a brief history of the Allegheny County Sanitary Authority (ALCOSAN) is in order.

In 1945, under the Clean Streams Act passed by the Pennsylvania Legislature, the City of Pittsburgh, along with neighboring municipalities and industries, were ordered to cease the discharge of their untreated wastes into the waters of the Commonwealth of Pennsylvania. The Allegheny County Sanitary Authority (better known as Alcosan) was incorporated for the purpose of handling this problem and to handle it on a county-wide or regional basis.

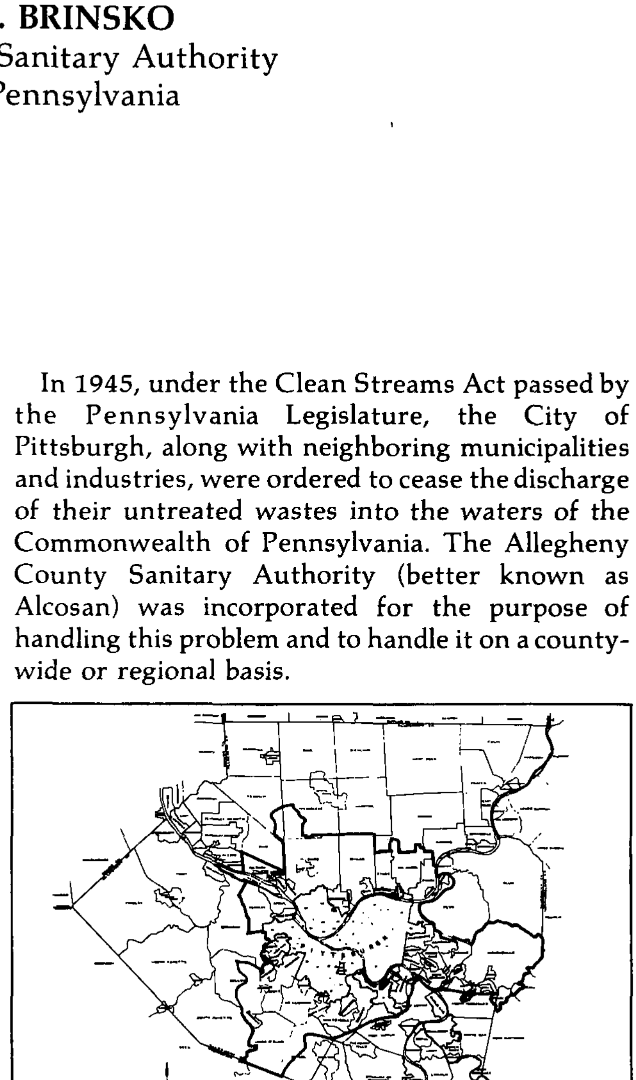

Figure 1: Service Area.

Alcosan serves the City of Pittsburgh, 75 municipalities and approximately 7000 industries, an area of 225 square miles with a population of 1,-250,000 (Figure 1). The wastewater collection system includes 69 miles of interceptors which vary from eight to twelve inches in the outer-most areas to 10½ feet in diameter at the Main Pump Station at the treatment plant. It generally follows the banks of the three rivers and two large creeks, and is almost entirely gravity flow with the exception of three small pumping stations and three ejector stations (Figure 2). Approximately 39 miles of the interceptor system are in deep rock tunnel. The treatment plant is located in the City of Pittsburgh, three miles downstream from the Golden Triangle on the north bank of the Ohio River.

Alcosan's wastewater treatment facilities are spread over 48 acres and cost $18 million to construct in 1956. The construction cost of the 69 miles of interceptor sewer lines, including pumping and ejector stations was $64,500,000. The complete construction costs for all facilities amounted to $100 million and was entirely financed by a bond issue. The Bonds are being redeemed from revenue received by Alcosan from sewage charges, based on water consumption. The current rate is 37½ cents per 1000 gallons.

From 1959 to October 1973, the facilities were rated as providing intermediate treatment but in reality were only slightly better than primary. With an average flow of 150 mgd, BOD removal averaged 35 percent and suspended solids 55 percent. The average total solids removal was 135,000 lbs. per day with the balance of over 90,000 lbs. discharged into the Ohio River. The settled solids, at a concentration of six percent were pumped to tanks where it was thickened or concentrated to 16 to 20 percent by an anaerobic flotation process (Laboon process) This process entailed heating the sludge to 100° F, and then pumping it into large holding tanks where it was allowed to stand for three to five days. Escaping carbon dioxide gases carried the sludge to the surface. The subnatant liquor was withdrawn and returned to the head end of the plant for treatment. The concentrated solids were pumped to the incinerator building, flash-dried, and incinerated.

Final disposal of sludge solids was accomplished in one or more of the four C.E. Raymond Flash-Drying incinerators (Figure 3). In the flash-drying process sludge particles are dried in suspension in a

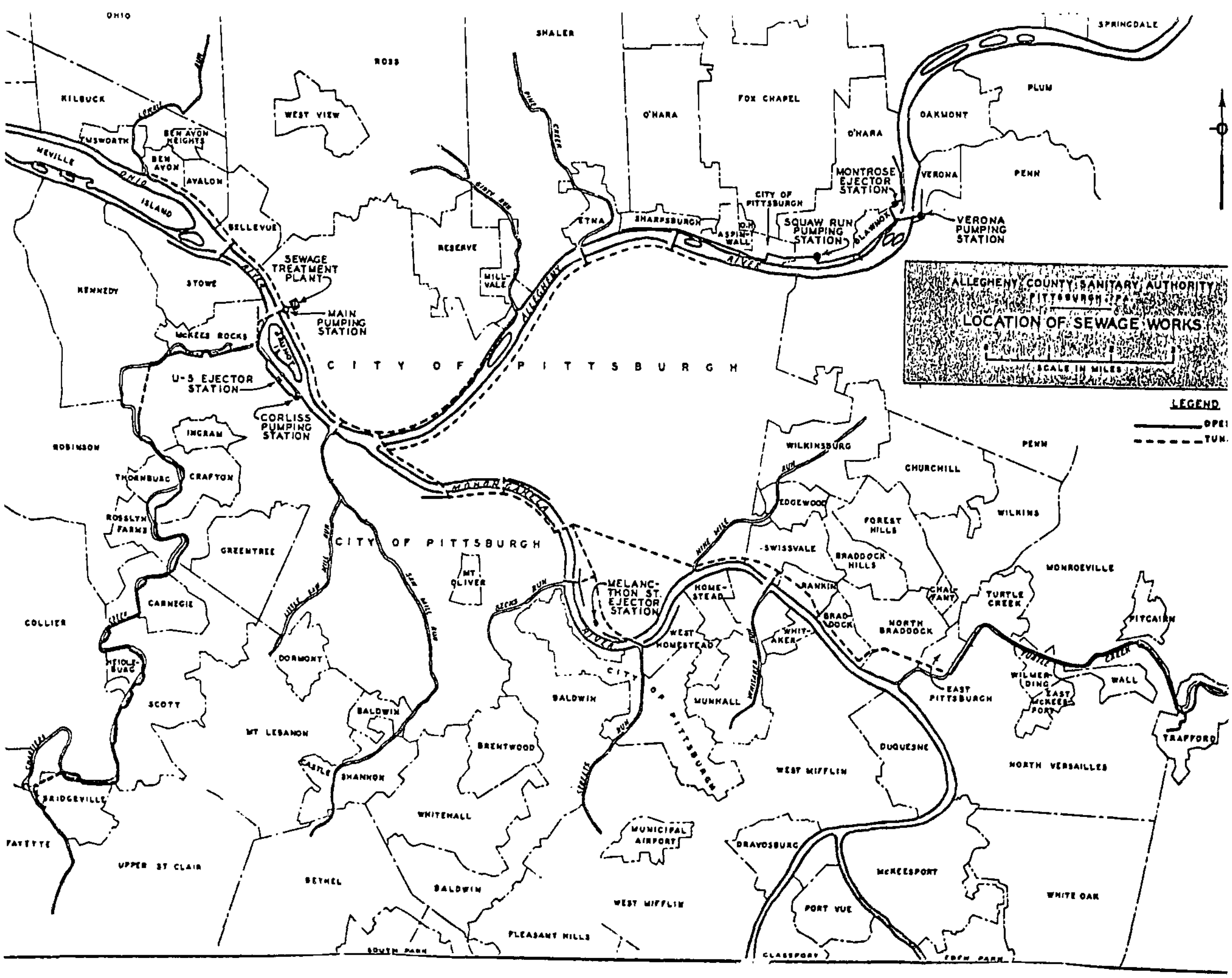

Figure 2. Location of Sewage Works.

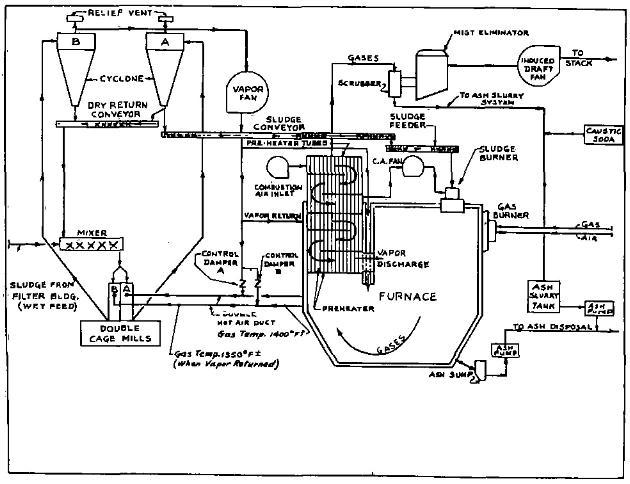

Figure 3: Flow Diagram for Sludge Incineration.

stream of hot gases, removing instantaneously almost all of the moisture. The concentrated primary sludge containing 16 to 20 percent solids were pumped to the mixer of the flash drying system where it was blended with previously dried sludge. The blended semi-moist sludge was fed to the dual cage mills where it contacted the hot gases from the incinerator. In the cage mills, drying was accomplished in a matter of seconds. The fine dried sludge particles were dispersed throughout the hot gas stream, and from the cage mills, the gas-borne particles were carried to cyclone separators to remove the dried sludge from the moisture laden and considerably cooled gases. A portion of the dried sludge was automatically returned to the mixer for blending with incoming wet concentrated sludge and the remainder was fed by closed conveyors to the incinerators for burning. Malodorous gases produced during the evaporation process were drawn into the deodorizing section of the furnace for destruction.

In 1970, Alcosan completed the first step in a $48,000,000 modernization plan designed to further upgrade plant performance. At that time, the coal fired incinerators were converted to clean-burning natural gas.

From 1960 to 1973, Alcosan concentrated or thickened an average of 27,584 dry tons of solids a year at a cost of $8.68 per dry ton. Incinerator costs averaged from $12.10/dry ton in 1961 to $49.09/dry ton of solids in 1972. The concentrated sludge averaged 16 percent solids and had a thermal value of 6000 BTU/pound dry solids. With an 84 percent water content, auxiliary fuel was required to maintain a specified combustion temperature. In 1970, when coal and gas were used as auxiliary fuels, an average of 0.4 lbs. of coal/lb. of dry solids along with 1.1 cu. ft. of gas/lb. of dry solids was necessary to complete the combustion cycle.

In October 1973, the secondary treatment facilities, utilizing the step-aeration activated sludge process were completed and put into operation (Figure 4). BOD removal now averages 91 percent and suspended solids 90 percent. Total solids removal was increased to 200,000 lbs./day. At Alcosan, activated sludge is not wasted from the final clarifiers but is returned to Pass 1 of the 4-Pass aeration system. Solids in Pass 1 are maintained around 10,000 parts or one percent. Activated sludge is wasted from Pass 1 to the head-end of the existing primary sedimentation tanks where it is mixed with the incoming raw sewage and resettled with the primary solids. This mixture of raw and waste activated sludge solids at a concentration of five percent are pumped from the primary sedimentation tanks through disintegrators and into mixing tanks where slow speed mixers insure a homogeneous mixture prior to sludge conditioning by polymer application. The sludge is then pumped to the vacuum filters. A battery of ten 575 square feet stainless steel coil-type filters dewater the combined sludge. The dewatered sludge at 20 to 30 percent solids is then carried by belt conveyors to the existing incinerators. The incineration process is the same as was employed for incineration of concentrated primary sludge. The incinerator ash together with the residue from the Venturi wet type scrubbers is settled in the existing ash settling tanks. The supernatant from these settling tanks is returned to the head end of the plant for treatment. The ash is hauled to a sanitary landfill properly approved by the regulatory agencies.

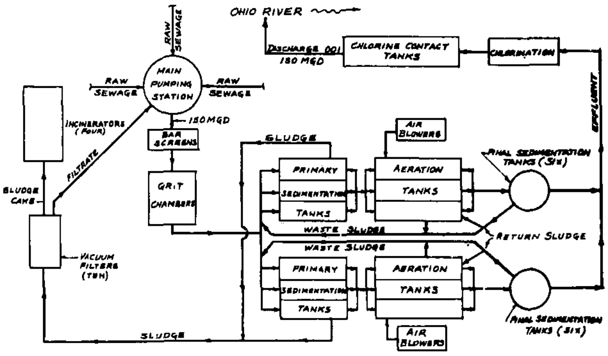

Figure 4: Schematic of Wastewater Flow, Alcosan Wastewater Treatment Plant, Pittsburgh, Pennsylvania.

The present incinerators actually are evaporators of water, and were designed to evaporate water from sludge with an 84 percent water content using supplemental heat. The greater solids concentration of the vacuum filter cake have markedly increased the capacity of the incinerators. Figure 5 shows the amount of wet sludge that can be incinerated at sludge solids content of 16 percent, 20 percent and 25 percent. It should be noted that a constant amount of water is being evaporated. Also significant is the marked increase in the pounds of dry solids that can be disposed of through a given incinerator. Thus, because of higher solids concentration in the vacuum filter sludge cake, the efficiency of the burning process is greatly increased. Gas consumption in 1973 was reduced by 40 percent over 1972. The savings of 248 million cu. ft. is enough gas to serve about 1340 homes for one year.

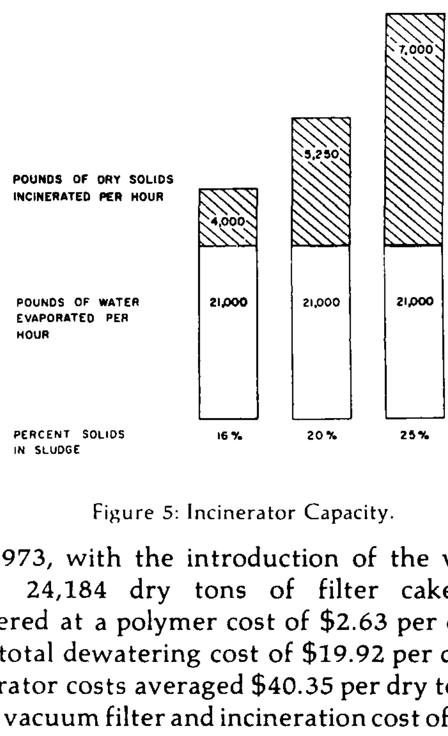

Figure 5: Incinerator Capacity.

In 1973, with the introduction of the vacuum filters, 24,184 dry tons of filter cake were dewatered at a polymer cost of $2.63 per dry ton and a total dewatering cost of $19.92 per dry ton. Incinerator costs averaged $40.35 per dry ton with a total vacuum filter and incineration cost of $60.27 a dry ton. The filter cake averaged 22 percent solids and had a BTU value of 7800 BTU/lb. dry solids. Auxiliary gas consumption amounted to 5.7 cu. ft./lb. dry solids.

Of course, auxiliary fuel requirements will vary with an increase or decrease in solids content, sludge volatile content, heat loss from the incinerators, presence of incombustible chemicals, and excess air usage. Fuel costs can also be reduced by eliminating or reducing temperature cycling. Since shutdown or start-ups of incinerators accounts for as much as 180,000 cu. ft. of gas per incident, the largest and easiest reduction in fuel consumption can be obtained by eliminating or reducing many of the start-ups or shut down incidents.

To say the least, sludge disposal by incineration is the most costly of all methods of disposal. Alcosan is no exception to this. Thirty-seven percent of our operating budget is tied in with our incinerator operation with 50 percent of our overall maintenance budget going towards the up-keep of the incinerators. As reflected earlier, disposal costs are high and the problems are many.

Alcosan has experienced its share of problems with the incineration of solids. In 1959, shortly after the start-up of the incinerators, sludge odors were detected in our stack gases. We were flooded with complaints. The odoriferous drying vapors were short circuiting and going out into the stack. Studies were conducted by our staff and our consultants, Metcalf & Eddy, and Combustion Engineering Inc. Modifications were made to the furnaces. Four new ports, 2 feet by 5 feet were cut into the target wall so that the discharge of four gases was directed into the combustion chamber, the hottest part of the furnace. A stainless steel baffle attached to the bottom of the target wall and extending 32 inches into the combustion chamber increased the contact time of the foul gases with the high temperatures to three seconds. Studies also indicated that to destroy odors at Alcosan a combustion chamber temperature of 1300° F was needed. The increased contact time, the four new ports directing the foul gases into the hot part of the furnace, and slightly higher preheater temperatures of 1300° F all combined, eliminated our odor problem.

The start-up of our new vacuum filter operation in 1973 brought a return of the problem experienced in 1959: a flood of odor complaints. Odors were detected coming from the three ventilating systems from within the vacuum filter building. One system handles the air from the basement and the first floor, the second system removes the air from the vacuum filter floor with the third system handling the gases from the ten separate vacuum pumps that are designed to mechanically remove the water and with it, foul gases from the sludge. The air from the three systems is ducted through a one inch thick activated carbon filter and then discharged to the atmosphere. Our investigations revealed the activated carbon that was supposed to have a life of one year was completely spent in a matter of a couple months. An attempt to have the carbon regenerated here in Pittsburgh failed for, as yet, no one was set up to refire the carbon. Hoping to save time and because of the municipal authority act* a contract was set up for the purchase of an-

*Municipal Authority Law—Any purchase in excess of $1,500.00 has to be advertised and set up for competitive bidding.

other set of filters. However, with President Nixon's wage and price control, Phase IV prohibited the manufacturer of the filters to raise the cost of the filters. The manufacturer refused to make the filters. New carbon was purchased and the filters recharged. The spent carbon was sent out to a local firm that was finally able to regenerate activated carbon. This was not the answer for the life of the carbon was greatly reduced by high quantities of sulfides in the sludge.

In an effort to alleviate the odor situation, experiments were conducted utilizing a chemical to oxidize the odor producing sulfides. Chlorine dioxide was found to be very effective. An application of 0.23 ml/gallon of sludge controlled the odors to an acceptable level. However, this was only a temporary solution and an expensive one for the chlorine dioxide dosage had to be increased 0.8 ml/gallon and resulting costs were $5.90 per dry ton of solids.

We feel that a permanent solution to our problem is thermal destruction of the odoriferous gases. Our consultants were instructed to redesign the exhaust system and duct the foul gases from the vacuum pumps into the incinerators for final destruction. However, such modifications are not made instantly. Drawings and specifications had to be drawn up and a contract let. On May 17, 1974 the Contractor started work on the necessary revisions.

During the period of redesigning our foul air system, additional experiments were conducted utilizing hydrogen peroxide to oxidize the odor producing sulfides in the sludge. Initial tests indicate that 0.18 ml/gallon of sludge reduced the soluble sulfides to .02 ppm a level supposedly free of odors. However, the quality and age of the sludge will affect greatly the quantity of hydrogen peroxide necessary to reduce the level of sulfides in the sludge and thus treatment costs. The cost of hydrogen peroxide treatment averages $.79 per ton of dry solids at an application of 0.36 ml/gallon of sludge. Recently hydrogen peroxide was added at a rate of 2.6 ml/gallon of sludge, resulting in a cost of $5.61 per ton of dry solids. Without a doubt, it has proven to be the most effective chemical for combating our odor problems. However, escalating dewatering and odor control costs could justify the evaluation of the Zimpro process as a possible substitute for the present methods employed by Alcosan.

In addition to the odor problems, incinerating the mixture of primary and waste activated solids also has created a problem. The increased heat value of the sludge has resulted in higher incinerator temperatures. In the past combustion chamber temperatures were normally around 1650° F. However, we now find the temperatures to be around 1900° F and a considerable amount of slagging occurs. The furnaces must be taken off line to remove the accumulation of slag, resulting in the loss of valuable furnace time. To reduce the temperature and eliminate the slagging problem a new duct system has been designed to carry furnace combustion air into the upper part of the combustion chamber.

With all the problems associated with sludge disposal by incineration, why then did Alcosan elect to go this route in the first place? In 1950, a study of the various methods of sludge disposal in primary treatment plants revealed that primary sludge was low in nitrogen and thus unsuitable for use as commercial fertilizer. In addition, the low auxiliary fuel cost coupled with reduced availability of land near Pittsburgh or any other metropolitan area, made it more advantageous for Alcosan to go to sludge disposal by incineration. Would this be true today? Yes and No. To incinerate just to reduce the overall quantity is not the answer. However, in as much as solid waste (garbage) is also a problem, the answer may be the incineration of a mixture of sewage solids and solid waste materials with the generation of steam as a final product, a product that today is in great demand.

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PASTEURIZATION OF LIQUID DIGESTED SLUDGE

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ABSTRACT

Digestion of sludge removes most, but not all, of the pathogens and parasites that can be harmful to man and animals. Although there is no evidence that land spreading of digested or otherwise stabilized sludge has caused disease to man or animals, the concern that the remaining pathogens may contribute to disease cannot be overlooked. Pasteurization, an effective method for disinfecting liquid digested sludge, is discussed. Topics covered are pasteurization temperature and time relationship, heat required, fuel sources, transferring and dispersing the heat with liquid sludge, equipment, estimated pasteurization costs, and maximum temperature for applying pasteurized sludge on lawn grasses.

The conclusions are that pasteurization at 70°C for 30 to 60 minutes destroys pathogens; sufficient methane gas, from anaerobic digestion, is available as the fuel source; direct steam injection and efficient mixing of the steam and liquid sludge is recommended; costs approximate ten dollars per ton of sludge solids for small plants; and cooling the pasteurized sludge to 60°C is sufficient to permit its use on lawn grasses.

INTRODUCTION

Four broad groups of pathogens that can be disseminated by sewage sludge are viruses, bacteria, cysts, and öocysts of protozoa and worm eggs. Sludge digestion removes most, but not all, of the pathogens and parasites that can be harmful to man and animals.

There is no evidence that proper land spreading of digested or otherwise stabilized sludges, which is a widespread practice, has caused disease to man or animals. Nevertheless, the concern of health authorities that the pathogens may contribute to human and animal diseases cannot be overlooked. Disinfection may be needed where people or animals come into contact with sludge.

Pasteurization is an effective method for disinfecting sludge. In West Germany and Switzerland, for example, pasteurization is required when the sludge is spread on pastures during the summer growth season.

Pasteurization Effectiveness on Sludges

Pasteurization implies heating to a specific temperature for a time period that will render harmless, or destroy, undesirable organisms in sludge. Roediger[1] has shown (Table 1) that pasteurization at 70°C (158°F) for 30 minutes destroys pathogens found in sludge.

Strautch[2] followed the destruction of various types of salmonella found in humans and animals. He showed that pasteurization at 70°C (158°F) for 30 minutes destroyed pathogenic intestinal bacilli in digested sludge.

Pasteurization of digested liquid sludge is being studied at the National Environmental Research Center, Cincinnati, Ohio. In laboratory tests, direct steam injection was applied to about 0.014m^3 (3.75 gallons) digested sludge in a 0.019m^3 (five gallons) carboy, and in a field test to about 3.4m^3 (900 gallons) digested mixed sludge held in a 6.8m^3 (1,800 gallons) tank truck. Test results are shown in Table 2. Sludge temperatures of 75°C (167°F) for one hour destroyed pathogens and reduced indicator organisms to less that 1,000 counts/100 ml

TABLE 1
Temperature and Time for Pathogen Destruction in Sludges

Microorganisms	*Exposure time (minutes) for destruction at various temperatures (° C)*				
	50	*55*	*60*	*65*	*70*
Cysts of Entamoeba histolytica	5				
Eggs of Ascaris lumbricoides	60	7			
Brucella abortus		60		3	
Corynebacterium diphtheriae		45			4
Salmonella typhi			30		4
Escherichi coli			60		5
Micrococcus pygogenes var. aureus					20
Mycobacterium tuberculosis var.					20
Viruses					25

(below detectable limits). At 70°C (158°F) for one hour, the pathogens were destroyed though coliform indicator concentrations sometimes remained above 1,000 counts/100 ml.

These studies show that pathogens and parasites in liquid digested sludge can be destroyed or inactivated by pasteurizing at 70°C for 0.5 to one hour.

Requirements for Pasteurizing Liquid Digested Sludge

The major factors in pasteurizing liquid digested sludge are the heat required, fuel sources, method for transferring and dispersing the heat throughout the liquid sludge and type of equipment employed. Although the solids concentration in liquid digested sludge varies, five percent solids will be assumed.

Heat Required

The assumptions to determine the heat required for one ton (English) of digested solids at five percent solids concentration in liquid sludge are:

1. The amount of liquid digested sludge is 2,000 lb/0.05 or 40,000 lb (4,800 gallons).
2. Ambient temperature of the liquid digested sludge is assumed to be 17°C (63°F). Pasteurization temperature is 70°C (158°F).
3. Twenty percent additional heat is assumed for maintaining 70°C for 0.5 to one hour.
4. Specific heat capacity, (Btu/(lb) (°F), is 1.0.

The total heat required is:

(40,000) (1) (158-63) (1.2) = 4.6×10^6 Btu/ton of sludge solids*

Fuel Sources

Two practical sources of fuel are:

1. Purchase of fuel; that is, oil or natural gas. Both natural gas and Number 2 fuel oil are clean burning fuels and do not require preheating. However, these fuels are restricted in their availability. Number 6 oil is more available but its use requires preheating and sophisticated air pollution equipment. Treatment plants using aerobic sludge digestion will have to purchase fuel for the pasteurization treatment.
2. Using methane gas produced from anaerobic digestion as fuel is technically feasible. Raw sludge contains about 60 percent volatiles. About 50 percent of the volatile solids are destroyed by digestion and 70 percent of the solids remain after digestion. Therefore, the amount of raw sludge sent to the digester is 1/0.70 or about 1.43 tons. Thus, about 0.43 tons (860 lb) of volatiles are destroyed by digestion.
   The fuel value of the methane gas for each pound of volatiles destroyed is about 10,000 Btu[3]. The heat content available is, therefore,

*To convert Btu on (English) to kilocalories/ton (metric) multiply by 0.278.

TABLE 2
Pasteurization Test Results[7]

Test No.(1)	Temp. 0° C	Time (hours)	Organisms/100 ml: Salmonella sp.	Pseudomonas aeruginosa	Total aerobic counts	Fecal coliform	Fecal streptococci	% Dilution after past.
L-1	13.5[2]		7.3	20	2.5 x 10^6	6 x 10^5	16 x 10^4	
	59-64[3]	1	N.D.[4]	N.D.	2 x 10^6	9000	B.D.L.	
		2	N.D.	N.D.	1 x 10^5	B.D.L.[5]	B.D.L.	18
L-2	15		>23	>9.1	3.4 x 10^8	1.5 x 10^6	30 x 10^4	
	60-69	1	N.D.	N.D.	7 x 10^5	B.D.L.	B.D.L.	32
L-3	16		9.3	21	7 x 10^7	7.7 x 10^6	2.3 x 10^6	
	63-66[6]	1	N.D.	20	6.3 x 10^6	6000	9 x 10^4	14
L-4	15		23	150	2.5 x 10^8	2 x 10^6	5 x 10^6	
	67-75	1	N.D.	N.D.	6.4 x 10^6	B.D.L.	B.D.L.	
		2	N.D.	N.D.	1.3 x 10^6	B.D.L.	B.D.L.	22
L-5	30		29	>1100	1.7 x 10^9	9.9 x 10^6	2.7 x 10^6	
	68-73	1	N.D.	N.D.	<3 x 10^6	5000	5000	12
L-6	18		3	7.3	1.2 x 10^8	1.9 x 10^6	6.5 x 10^4	
	77-85	1	N.D.	N.D.	6 x 10^5	B.D.L.	B.D.L.	52
L-7	14		240	43	1 x 10^8	1 x 10^6	6.5 x 10^4	
	87-91	1	N.D.	N.D.	3 x 10^6	B.D.L.	B.D.L.	59
Using Steam Gun								
P-1	26		>240	93	7.9 x 10^7	5 x 10^5	1.7 x 10^5	
	38-55	1.5	>240	N.D.	1.7 x 10^7	5 x 10^7	4.2 x 10^4	10
Through Copper Tube with 12 3/16-inch holes								
P-2	25		>240	16	1.8 x 10^8	8.4 x 10^6	2.1 x 10^5	
	70-83	1	N.D.	N.D.	4.4 x 10^5	B.D.L.	B.D.L.	
		1.5	N.D.	N.D.	4.5 x 10^5	B.D.L.	B.D.L.	
	59[7]		N.D.	N.D.	3.8 x 10^5	B.D.L.	B.D.L.	58

Notes:
(1) L-numbers — Laboratory Tests
P-numbers — Large-Scale Tests
(2) Original Digested Sludge Temperature (typical)
(3) Pasteurization Temperatures (typical)
(4) N.D. — None Detected (<3/100 ml)
(5) Below detectable limits of analysis (<1000/100 ml)
(6) Presence of *Pseudomonas aeruginosa* and relatively high fecal streptococci suggests that heat did not penetrate the sludge.
(7) After cooling with air to 59° C.

860 lb x 10,000 Btu/lb of volatiles destroyed or about 8.6 x 10^6 Btu. Assuming 20 percent loss of fuel value in producing the heat energy (e.g., in a steam boiler) leaves about 6.85 x 10^6 Btu. This quantity of heat energy is more than sufficient to meet the need for 4.6 x 10^6 Btu/ton of digested sludge solids at five percent concentration. Methane gas from anaerobic digestion is successfully being used for large-scale pasteurization of liquid digested sludge at Niersverband, Germany[4].

Transferring and Mixing the Heat with Liquid Sludge

Direct steam injection is more effective than indirect heat exchange. Both organic fouling and inorganic scaling on heat exchanger surfaces reduce the heat transfer efficiency[4]. In one study[5], about 30 minutes were required to heat water to 100 psi in a 200-gallon reactor fitted with a steam jacket and coils; however, four hours were required to heat sludge in the same reactor. Because direct steam injection is used, the steam should not contain chemicals that are incompatible with land spreading of pasteurized digested sludge. Extra precaution is required to insure proper deaeration and softening of the boiler feed water to protect the steam boiler from excessive scaling and corrosion.

For complete effectiveness, each sludge particle (and solution) must receive the full pasteurization treatment. Because the thermal conductivity of water* is low**, it is important to avoid thick pockets of unstirred liquid sludge so that heat can be transferred in a reasonable time period. Estimates were made of the time needed to reach pasteurization temperatures for unstirred liquid digested sludge layers (semi-infinite) ranging from 0.625-cm to 5.08-cm (¼ to 2 inches) thick using the unsteady-state heat transfer procedures described by McAdams[6] and the following assumptions:

1. Heat transfer by convection is negligible because thick sludge particles are a non-Newtonian liquid with a yield factor that inhibits convective heat transfer.
2. Heat can be transferred through the liquid sludge layer two ways. The first is heat transfer in one direction only, from the bulk of the liquid sludge through the liquid sludge layer to the walls of the pasteurizer. The other is two-direction heat transfer, that is, heating the liquid sludge layer simultaneously from opposite directions perpendicular to the liquid sludge layer.

The time estimates are shown in Table 3 for two sets of heat transfer conditions. Note that the heating time increases by a factor of four when the thickness of the unstirred sludge layer doubles. Also, two-direction heat flow reduces by one fourth the time needed for heat transfer, and increasing the heat transfer driving force reduced the time needed for pasteurization of the liquid sludge layers approximately in proportion to the change in the ultimate driving force. Nevertheless, even under more favorable conditions, the time estimates for heat to be transferred through thick unstirred liquid sludge layers are relatively long, thus demonstrating why thick pockets of unstirred liquid sludge must be avoided. In-line heating by injecting steam into the pipe through which the liquid sludge is flowing may be more effective than injecting steam directly into a large tank. Also, a multiple lance that ejects steam in a circular motion may possibly provide enough mixing to prevent thick unstirred liquid sludge pockets.

Type of Equipment

Two major equipment items needed for pasteurization of liquid digested sludge are a steam boiler to produce the steam and a tank to hold the digested sludge during pasteurization. This equipment need is deliberately oversimplified to show that only limited information is available on pasteurizing liquid sludges. For instance, this writer is unaware of any treatment plant pasteurizing liquid sludges in the U.S. In Germany and Switzerland, pasteurization is used to disinfect liquid sludge spread on pastures during the summer growth season.

Triebel[4] describes sludge pasteurization at the plant at Niersverband, Germany. Heat recuperation is used to conserve the heat energy. Figure 1 shows the steps in a one-stage heat recuperation pasteurization process. From the concentrated digested sludge tank, the sludge is pumped into a preheating chamber where it is heated from 18°C (64°F) to 38°C (112°F) by the vapors from the blow-off tank under 0.1 atm. From the preheater, the sludge is pumped at 1 atm to the pasteurizer where direct steam injection heats the sludge to about 70°C (158°F). The sludge is then transferred to a retention tank where it is held for 30 minutes. Next, the sludge is transferred to the blow-off tank where it cools to 45°C (113°F) under 0.1 atm. The vapors are used to preheat the incoming new sludge. The sludge is further cooled to 35°C (99°F) at 0.051 atm in a second blow-off tank. The vapors from the second retention tank are condensed and discarded. This one-stage heat recuperation pasteurization sludge process is considered economical if the minimum daily sludge flow is 200 to 250 m^3/day (53,000 to 66,250 gpd). If the sludge quantity is 400 to 500 m^3/day (106,000 to 132,500 gpd), two-stage heat recuperation is considered economical. For over 1,000 m^3/day (over 265,000 gpd) sludge flow, three-stage heat recuperation appears economical.

Even with the energy crisis and high fuel costs, recovery and reuse of the heat from pasteurized liquid sludge may not be feasible for smaller treatment plants because of the substantial capital investment required for heat vapor compressors.

A pilot field test conducted at the Lebanon Sewage Treatment Plant near Cincinnati, Ohio, demonstrated that liquid digested sludge can be pasteurized in a tank truck. This pasteurizing approach may be useful for small treatment plants. Approximately 3.4 m^3 (900 gallons) of digested mixed sludge was pumped into a 6.8 m^3 (1,800 gallons) tank truck. Steam was directly injected into the liquid sludge using an 8.5 liter/minute (2.2 gpm) condensed steam cleaner. The liquid sludge temperature was increased from 25°C (77°F) to 80°C (176°F) in 1 hour. The wet steam temperature was approximately 118°C (244°F). The temperature was maintained between 70°C (157°F) and 83°C (181°F) for approximately 30 minutes. The destruction of pathogens is shown in Table 2,

*Liquid sludge at five percent solids concentration contains 19 parts water to one part solids.

**0.035 cal/(hr) (cm^2) (°C/cm) at 20°C or 0.34 Btu/(hr) (ft^2) (°F/ft) at 68°F.

TABLE 3
Hours Needed to Reach Pasteurization Temperature of Unstirred Liquid Sludge Slabs with Thickness Range from 0.25 Inches to 2 Inches

Sludge thickness (In.)	Condition A: Sludge temperature 20° C; Bulk sludge temperature 75° C; Desired sludge temperature of slab 70° C	Condition B: Sludge temperature 20° C; Bulk sludge temperature 80° C; Desired sludge temperature of slab 65° C
CASE 1: One-direction, unsteady-state heat transfer		
0.25	0.14	0.06
0.50	0.57	0.22
0.75	1.29	0.5
1.00	2.3	0.9
2.00	9.25	3.6
CASE 2: Two-direction, unsteady-state heat transfer		
0.25	0.04	0.02
0.50	0.14	0.06
0.75	0.32	0.13
1.00	0.57	0.22
2.00	2.3	0.90

Test No. P-2. The 58 percent dilution of the pasteurized liquid sludge was due to using wet steam and a poorly insulated truck. The theoretical dilution is a minimum of eight percent, though in practice 15 percent is probably more realistic with dry steam. Closer temperature control could be achieved by better control devices and experience.

Costs for Pasteurizing Liquid Digested Sludge

The cost of pasteurization was calculated by Triebel in 1967[4] for German conditions (Table 4). He showed that pasteurization cost per ton of sludge solids decreases with increased sludge flow. The heat for pasteurization was derived from the methane gas produced by anaerobic digestion and no heating costs were included.

Desk-top estimates were made for today's condition of the cost for pasteurizing one ton and four tons digested sludge solids per day. The assumptions are 20 percent heat loss in a steam boiler, operation of the pasteurization equipment two hours/day for one ton sludge solids and eight hours/day for four tons sludge solids, sizing the equipment to pasteurize 1.4 tons sludge solids (seven days liquid sludge accumulation over a five-day period), purchase of Number 6 fuel oil at $\$2.50/10^6$ Btu or use of methane gas from anaerobic digestion and one man-hour/pasteurization treatment.

Basis: One ton of digested sludge solids/pasteurization treatment.

Fuel Costs

$$\frac{4.6 \times 10^6 \times \$2.50}{1 \times 10^6 \times 0.80} = \$14.40$$

(The fuel cost has increased 3.5 times since a similar cost estimate was made in 1972)[7].

Capital Equipment Cost

Approximately 4.6×10^6 Btu is needed to pasteurize one ton of sludge solids at five percent concentration over a two-hour period. It is assumed that 80 percent, or 3.8×10^6 Btu is needed to raise the liquid temperature from 17°C to 70°C in one hour. Assuming steam at 1,100 Btu/lb, the size of the steam boiler is:

$$\frac{3.8 \times 10^6 \times 1.4}{1{,}100} = 4{,}840 \text{ lb of steam/hour}$$

Inquiry made of several small steam boiler suppliers indicates that the capital cost for the boiler and auxiliary equipment is about $6.75/lb of steam generated. The capital cost is estimated to be 4,840 (lb) x $6.75/lb = $32,700 for the steam boiler, plus $4,500 for pumps, pipes, and the pasteurizer tank (120 ft^3) for a total of $37,200. The average life of the equipment, when properly maintained, is about 25 years. At six percent interest, the annual cost factor is $37,200 x 0.0783 = $2,900/year or about $8/day. This is the capital cost for pasteurizing one ton of sludge solids/day. When pasteurizing four times/day, the capital cost is $2/ton of sludge solids.

The capital cost will increase by about 20 percent if methane gas is used instead of Number 6 fuel oil.

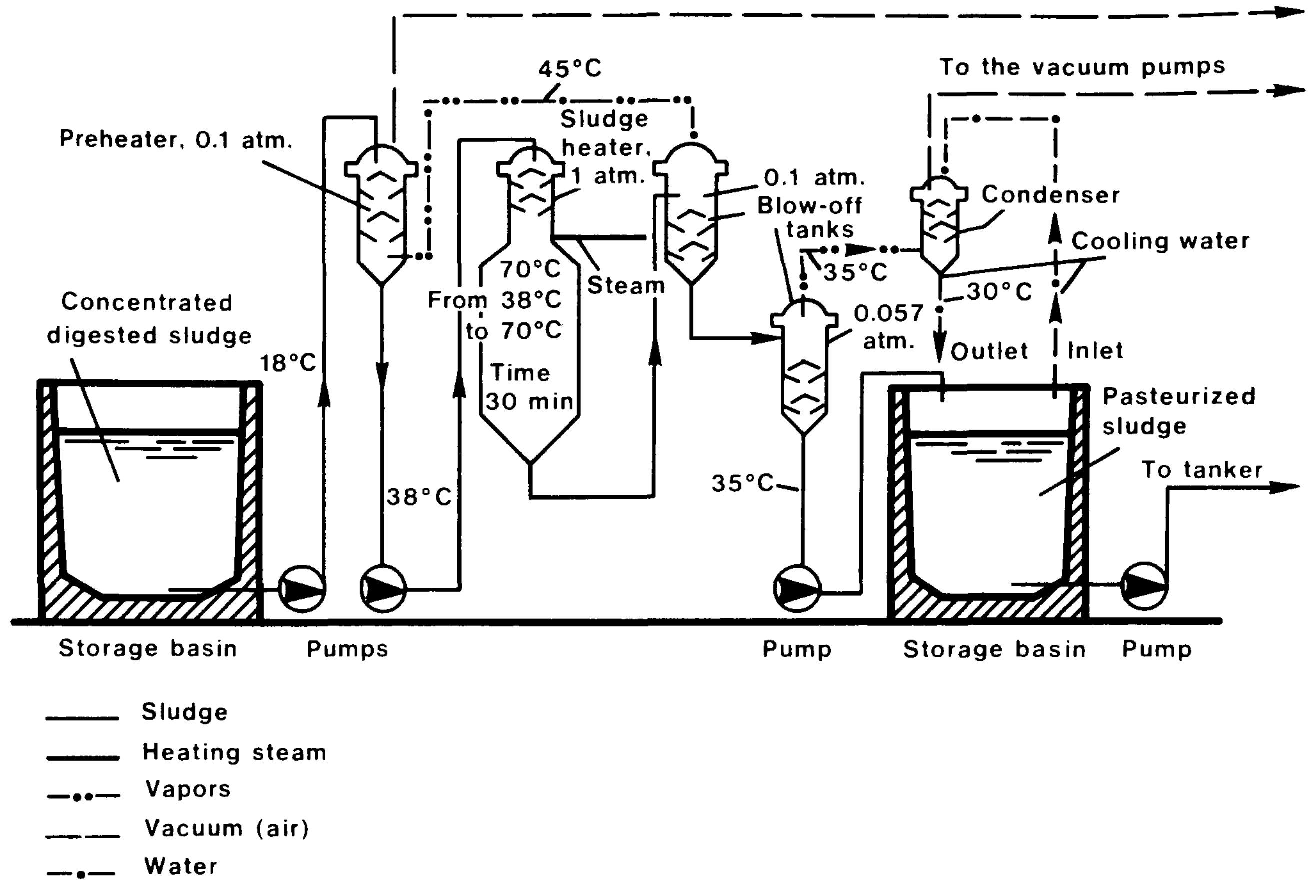

Figure 1: Diagram of Sludge Pasteurization in the Group-Sewage Plant of the Niersverband Viersen Illustrating One-Stage Heat Recuperation (After Triebel, Reference 4).

This additional capital cost is needed to clean the methane gas before use. However, the additional capital cost is usually less than the cost of fuel oil.

Labor Cost

Labor cost is $6/man-hour, plus ten percent for cleaning, maintenance, etc., or $6.60 for each 1.4 ton sludge solids pasteurized; or about $4.75/ton of sludge solids.

TABLE 4
Dollar Costs for Pasteurizing Digested Sludge*

Tons of digested sludge pasteurized annually	*Tons per day (365 day-year)*	*Cost per ton of sludge solids (1967)*
0.78×10^3	2.14	$8.60
1.56×10^3	4.28	6.42
5×10^3	13.7	1.85
10×10^3	27.4	1.30

*After Triebel[4]; 1967 rate of exchange, 4 German marks = $1.00.

Electrical Power, Chemicals, and Replacement Part Costs

These costs are minor when compared to other pasteurization costs. Electrical power needed is about 14 kw-hr per pasteurization treatment. Total cost of the electrical power plus chemicals (for corrosion control of the steam boiler) plus repair parts is estimated at $2/ton of sludge solids.

Summary of Pasteurization Costs

Total costs for pasteurization of one ton of sludge solids at five percent concentration in liquid digested sludge are:

1. One liquid sludge pasteurization/day

	Number 6 Oil	*Methane Gas From Anaerobic Digestion*
Heat energy	14.40	–
Capital cost	8.00	10.00
Labor	4.75	4.75
Electrical, chemical repairs	2.00	2.00
	$29.00	$17.00

2. Four liquid sludge pasteurization/day

	Number 6 Oil	*Methane Gas From Anaerobic Digestion*
Heat energy	14.40	--
Capital cost	2.00	4.00
Labor	4.75	4.75
Electrical, chemical repairs	2.00	2.00
	$23.00	$11.00

These figures show the cost saving of substituting methane gas instead of purchasing Number 6 fuel oil and operating the pasteurization facilities four times per day. Note that pasteurization costs still approximate ten dollars per ton of sludge solids for relatively small treatment plants.

If quick turn-around time is required for loading and unloading pasteurized liquid digested sludge, it may be of advantage to install a heated storage tank. No-cost estimate was made for a holding tank. Its cost will probably be a minor fraction of the total cost of pasteurization.

Maximum Temperature for Spreading Pasteurized Sludge on Lawn Grasses

Studies conducted at the National Environmental Research Center in Cincinnati showed that pasteurized sludge can be applied to growing grasses if the temperature at the soil surface does not exceed 60°C (140°F). Because evaporative cooling of sprayed sludge can reduce the temperature significantly and heat may be lost in transit, direct cooling may not be necessary in most cases. No adverse effects are expected if hot sludge is applied to bare soil before crops are started.

SUMMARY

1. Pasteurizing at 70°C (158°F) for 30 to 60 minutes destroys pathogens in digested liquid sludge.

2. Sufficient methane gas is produced by anaerobic digestion for the fuel needed to pasteurize digested liquid sludge.

3. Direct steam injection is more efficient than indirect heat transfer for pasteurizing liquid sludge.

4. Thick, unstirred sludge pockets must be avoided for effective pasteurization.

5. Small treatment plants can pasteurize liquid digested sludge at reasonable costs.

6. After pasteurization, liquid sludge needs to be cooled to only 60°C (140°F) before it is sprayed on grass.

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SLUDGE HANDLING AND DISPOSAL AT BLUE PLAINS

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ABSTRACT

Blue Plains Wastewater Treatment Plant is a regional facility serving most of the Metropolitan Washington Area. The plant is now undergoing expansion and the addition of advanced wastewater treatment. In the past, anaerobically digested sludge was all disposed on the land. At the present time both raw and digested sludge is undergoing disposal by a variety of techniques including land spreading, burial, composting, and thermal dehydration. For future disposal of sludge, a combination of methods, including land spreading, composting, thermal dehydration, and incineration are now under evaluation. The District's priorities are to work within all regulatory guidelines and process the sludge into a reusable commodity.

Overview of Blue Plains Plant

The District of Columbia Government, Department of Environmental Services operates the Blue Plains Wastewater Treatment Plant. The plant services a 725 square mile area including the entire District of Columbia and portions of Maryland and Northern Virginia. The current plant facilities include primary and secondary treatment, with sludge processing by anaerobic digestion, elutriation, and vacuum filtration (Figure 1). The plant was designed for 240 MGD, but operated at an average flow of 294 MGD during fiscal year 1973. Effluent quality averaged 49 mg/1 BOD_5 during that period.

A major construction effort at the site is now underway with completion scheduled for January 1, 1978. Flow capacity will be expanded to 309 MGD and advanced waste treatment will be added at a total cost of approximately $360,000,000.00. The effluent requirements will be: BOD_5 = mg/l, total phosphorus =0.22 mg/1, and total nitrogen = 2.4 mg/1. To meet these requirements, the plant will construct additional primary and secondary facilities, biological nitrification and denitrification reactors for nitrogen removal, and filtration and disinfection facilities (Figure 2). Ferric or aluminum salts will be added in a two-stage process for phosphorus removal. A solids processing unit which includes air flotation thickeners, vacuum filters and multiple-hearth incinerators will handle all sludges produced.

Sludge Disposal - Past

During the period from 1938 to the present, the plant went through several distinct changes in operation which resulted in improved treatment of wastewater concurrent with increased sludge production. From 1938 through 1960 the facility was only a primary treatment plant, with sludge processing by conventional anaerobic digestion, elutriation, and vacuum filtration. Sludge quantities gradually increased from an average of 19 to 33 dry tons per day. Final disposal was by application to farmland, use as a soil conditioner by the Federal government, or by burial, At that time the most important aspect of sludge processing was the production and use of methane gas which was burned to produce electricity to operate the entire plant.

Throughout the 1950's and 1960's government and private demand for the filter cake as a soil conditioner increased steadily. In 1960, secondary

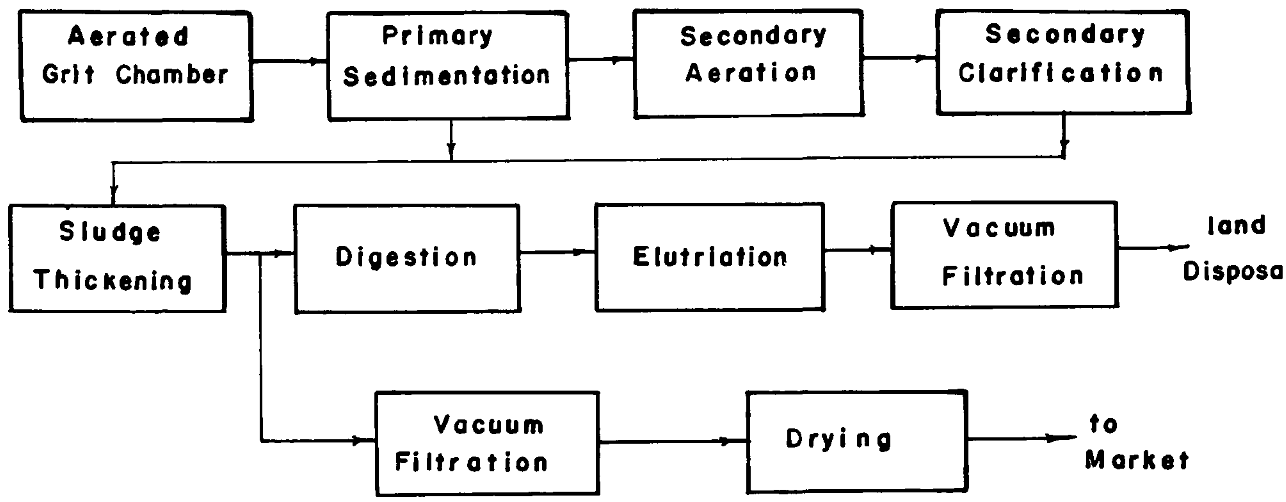

Figure 1: District of Columbia Wastewater Treatment Plant— Present Facilities.

treatment and high-rate digestion came on line and the quantities of sludge gradually increased. To make the sludge more acceptable, it was hauled to a yard on the plant site, mixed with earth (three parts dirt/one part sludge), limed, windrowed, and allowed to dry. The mixture was shredded and given to the public. In 1964 odor problems and reported cases of salmonella caused the Health Department to require sludge aging for one year prior to distribution and also to restrict its distribution during the summer months.

The sludge disposal problem became aggravated in the late 1960's when polymers for elutriation and filtration were first used. The polymers succeeded in increasing the capture of fines and greatly improved the wastewater quality, but sludge quantities doubled. Polymer treated sludge contained more moisture as discharged from the filter (75 - 80 percent) and also was not easily dewatered in the sludge yard. The sludge yard gradually became a large storage area and demand for the product dropped off considerably. In 1970, the plant started using contract haulers to dispose of the filtered sludge, and to clear the stockpile of sludge in the yard. Most of this sludge was then used in making top soil for the final cover of various landfill projects in the area. In 1972, the sludge yard was excavated for future construction of advanced waste

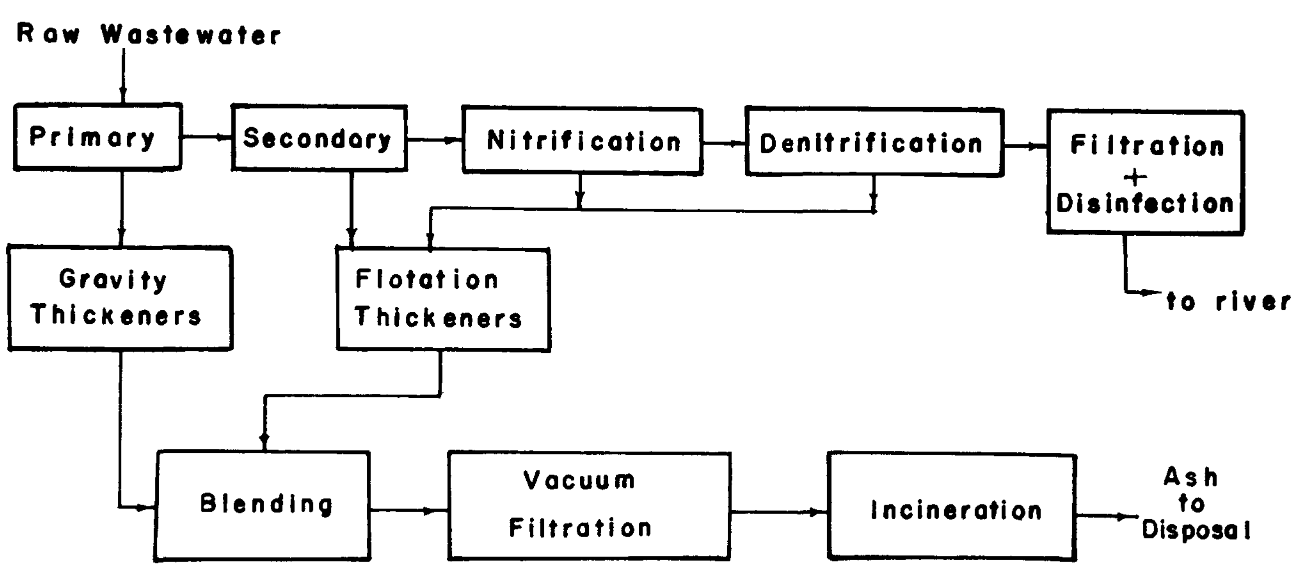

Figure 2: District of Columbia Wastewater Treatment Plant— Future Facilities.

TABLE 1
Sludge Quantities

Year	Wet tons per Day (% solids)	Disposal Cost ($/wet ton filter cake)
1939	60 (32.4%)	$1.25
1950	78 (30%)	$1.28
1961	106 (30.7%)	$2.00
1970	310 (24%)	
1973	418 (20.2%)	$6.85
1974	expected 550 (20-23%)	$8.25
1978	expected 2160 (20%)	

treatment facilities, allowing at present only a small area for emergency stockpiling.

Table 1 summarizes some of the historical quantities and costs for sludge disposal.

Sludge Disposal - Present

Currently, the production and disposal of sludge is tied to an interim agreement (until new incineration facilities are completed) among the local political jurisdictions. When the plant operates normally (primary plus secondary treatment), it produces an effluent quality of approximately 50 mg/l BOD_5 (120,000 pounds per day BOD_5 discharged to the river), and also an average of 310 wet tons per day of digested sludge as filter cake. Under the interim agreement, the plant has installed facilities to add metal salts to secondary treatment to reduce the BOD discharged to the river to less than 100,000 pounds per day (40 mg/l BOD_5). Such addition of chemicals to the required one-half of plant flow produces an additional 240 wet tons per day of undigested (raw) sludge as filter cake. The two types of sludges, raw and digested, are handled separately. For digested sludge filter cake the options for final disposal are either land spreading or composting. For the raw sludge filter cake the options are burial by the trenching method, composting or thermal dehydration.

Digested Sludge

LAND SPREADING. For the annual year 1973, the digested sludge was used for reclaiming marginal lands by plowing or discing into the soil. The hauling and final disposal was handled by a private contractor at a cost of $6.85 per wet ton. During that year, all available land sites in the District of Columbia for sludge disposal were exhausted, and the remainder went into Prince Georges County, Maryland for reclamation of marginal lands.

The year 1974 brought a new hauling contract at a new price ($8.25 per wet ton) and an increased public awareness as to final disposal sites and methods. At one point, EPA obtained a Federal court injunction preventing us from shutting down the plant because we could not dispose of the sludge. An agreement was finally reached between all local jurisdictions involved to each handle their fair share of the sludge. Sludge is now proportioned to each of the local counties based on their average wastewater flows.

Because of this increased local involvement, land disposal is, of necessity, becoming more of a science. All parties involved are taking precautions to protect against the possibility of health hazards, odor problems, and heavy metal contamination of the soils to which sludge is applied. Possible sites are divided into one of three categories; agricultural land, marginal land, and high-rate disposal lands. In all cases, health hazards are minimized by the use of special trucks for hauling, with sealed tailgates, sometimes tarpaulin covered. The sludge may not be stockpiled at the site for more than 24 hours and in general it must be buried under a layer of earth.

Disposal on agricultural land is subject to many restrictions. Only certain types of crops may be grown, such as corn and soybeans, and these may not be for direct human consumption. To protect against heavy metal uptake by plants, the pH of the soil must be maintained above 6.5 and a limit of 15 dry tons per acre is tentatively being proposed in Maryland. The exact application rate on agricultural land is calculated by the following formula:

$$\text{Dry tons per acre} = \frac{(8.15 \times 10^3)\,(\text{CEC})}{\text{zinc equivalent (mg/kg dry sludge)}}$$

CEC = cation exchange capacity of the soil
Zinc equivalent of sludge =Zinc + 2 (Copper)+8 (Nickel) expressed as mg/kg dry sludge

An additional requirement is that the cadmium content of the sludge must be 1.0 percent or less than the zinc concentration. If the cadmium content exceeds this value, the sludge may not be used on any agricultural lands. The above formula was developed by the University of Maryland, Department of Agronomy, based on some work performed by the U.S. Department of Agriculture.

Typical metal contents of Blue Plains sludge are shown in Table 2. The plant performs a composite sample analysis for metals biweekly. A procedure is now being established in Maryland whereby a farmer who wishes to receive sludge on his property can have the soil analyzed and a recommendation

TABLE 2
Heavy Metal Content of Blue Plains' Sludges

Metal	*Raw Sludge*		*Digested Sludge*	
Zinc	1200	mg/kg (dry)	2500	mg/kg (dry)
Copper	300	"	750	"
Nickel	35	"	45	"
Cadmium	9	"	24	"
Lead	400	"	780	"

for application rate determined by the local health department.

At this time cadmium is the most restrictive element and we are investigating possible sources in our wastewater collection system. When all the information is developed as to the cause-effect relationship of the elements we will intelligently be able to implement an industrial waste ordinance for users of the wastewater collection system.

The problem of heavy metal contamination in sludge must be faced no matter how the sludge is to be processed. Work is underway at the EPA-DC Pilot Plant to determine the fate of heavy metals in various wastewater treatment sequences.

Disposal of sludge on marginal lands is limited to fifty dry tons per acre, again because of possible heavy metal contamination. The sludge is generally plowed or disced into the soil. Because of odor and possible runoff problems, plowing is the preferred method. Land in this category includes gravel pits, beltway interchanges and land scheduled for recreational use.

High rate disposal of sludge is generally accomplished by the trenching method. Trenches approximately two to four feet deep and two feet wide are dug, filled with sludge, and covered with earth. The disadvantage is that the sludge is no longer a resource, and stabilization and dewatering may take up to five years. Up to 500 dry tons per acre may be applied by this method.

COMPOSTING. Sludge composting with wood chips is another currently operable process now under examination. Filter cake sludge is hauled twenty-one miles to a fifteen acre site at Beltsville, Maryland. The sludge cake is mixed with wood chips in a 3/1 chip to sludge ratio and piled into windrows five feet high. The windrows are turned daily for approximately fourteen days. The mixture is then screened and the wood chips recycled. The compost is aged for an additional thirty days in a tall pile to ensure pathogen destruction before distribution. To date nearly all the compost produced has been used by local agencies as a soil conditioner. The finished product is an excellent peat moss substitute.

The composting project is a joint effort with USDA's research laboratory at Beltsville and Maryland Environmental Services. The project originally grew out of a need to handle the interim produced raw sludge at Blue Plains. Raw sludge composting, although technically a viable process, produces undesirable odors for a site such as at Beltsville. Because of these odor problems, the composting of raw sludge is now limited to special research testing. The site is now handling routinely 50 wet tons per day of digested sludge without any problems. We are continuing work on the optimization of digested sludge composting and odor abatement with raw sludge composting. At the present time, D.C. considers that composting digested sludge is a viable option for its future needs, and we are in search of a more permanent, and closer site.

Raw Sludge Disposal

As mentioned above, the production of raw (undigested) sludge is necessary because of the interim treatment program. The disposal of this sludge is quite difficult because it is not biologically stabilized and therefore produces severe odor problems. In fact, the interim chemical treatment program has been sporadic due to numerous problems encountered with raw sludge disposal. Trenching has been tried but it is generally unfavorable except in emergency situations due to a lack of land disposal sites. Composting has been tried, as mentioned, but is restricted because of odors. Research on composting small batches of raw sludge, or blends of raw and digested sludges, is still underway. The only immediately available option now open to us is a thermal dehydration process. A contract negotiated between Maryland Environmental Services (MES), D.C. Department of Environmental Services, and a private concern will result in the Companys' processing up to 240 wet tons per day of raw sludge on a research-demonstration basis.

Their product, dehydrated sludge, will be marketed as a 6-4-0 organic fertilizer (6 percent nitrogen, 4 percent phosphoric acid, 0 percent potash). The contractor has built a single-train drying plant at the Blue Plains site. The final product (50-60 dry tons per day) is their property to market. If the market price of their product increases above a set value, D.C. and MES will also obtain a net lowering of the disposal price paid to the contractor.

The process is as shown in Figure 3. Vacuum filtered sludge is delivered in trucks and conveyed

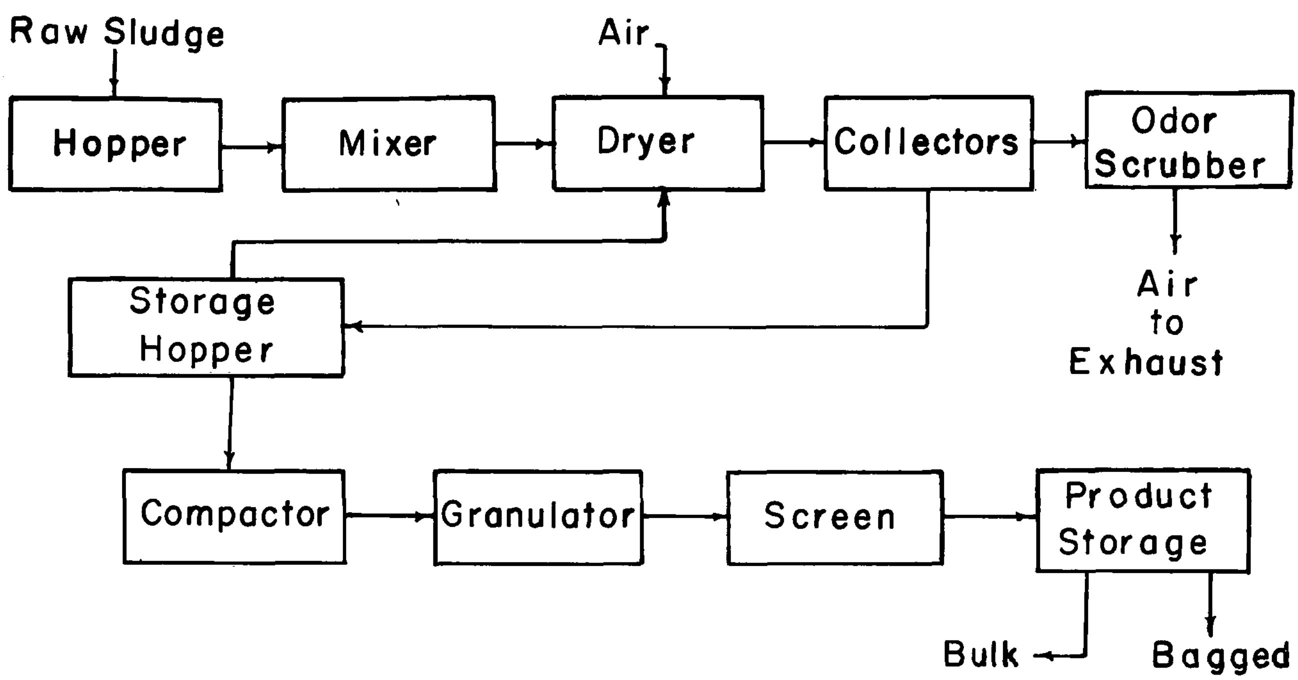

Figure 3: Sludge Drying Process.

to the wet sludge hopper. Sludge is pumped to the mixer, mixed with previously dried product and fed to the dryer. Air, heated to 1100°F, is blown into the dryer, a toroidal shaped unit. Dried sludge is collected in cyclone collectors and a bag house. The air is scrubbed with a chemical solution for odor control before discharge. The dried sludge is air conveyed to a storage hopper. From this hopper the product is either backmixed with fresh sludge or sent on to final processing, which includes compaction, granulation and screening. The final product, a pellet sized material is either shipped out in bulk or bagged and sent directly to market.

The fuel used for drying is now #2 fuel oil. We are in the process of designing a sludge gas pipeline and accessory equipment to be used as the primary fuel source.

Construction of the plant is now completed and they are now in the start-up phase of the project.

Sludge Disposal - Future

The scheduled expansion at Blue Plains will greatly increase the quantities of sludge to be processed. The new solids processing facilities have been designed for an average daily production of 431 dry tons per day. This includes all wastewater treatment sludges as well as all water treatment sludges produced in purifying the city's drinking water. To handle these quantities, a conservative, all-weather system has been designed. A new solids-processing building is nearing completion. It will house air-flotation thickeners for waste activated sludge, sludge blending tanks, thirty vacuum filters, and eight multiple hearth incinerators. The capital cost for the building, flotation thickeners, and blending units was approximately $13,200,000.00 The vacuum filter portion was bid at approximately $7,800,000.00. The incinerators are estimated to cost approximately $20,000,000.00.

The incinerators incorporate the best state of the art for controlling stack emissions. Pollution control equipment consists of a high energy venturi scrubber (40 inches of water pressure drop), a two-plate impingement jet scrubber, and a direct flame afterburner. The major operating expense for the incinerators will be the fuel oil requirements. At the average design rate, the usage will be approximately 15.6 million gallons per year of #2 fuel oil. Thirty percent of that total is required for the afterburner. We are currently awaiting EPA's approval to bid the incinerator portion of the solids processing facility.

Recognizing the high cost of incineration of raw sludge and the shortage of fuel, we are currently evaluating other methods for sludge disposal. The heavy metal content of our sludges are low enough, that with a good industrial ordinance, we should have little problem in meeting any proposed land disposal standards. Consequently, we have set our priorities to reuse the sludge on land whenever possible. Drawing upon the experience of the 1960's and the present time, we recognize the need to make the sludge acceptable for public and private use. But we also recognize the need for a multi-faceted disposal method, one that is not totally subject to the weather nor to any other biological or chemical upsets. The options include:

a) all raw sludge disposal, thermally dehydrated, marketed as fertilizer.
b) combination-raw sludge, thermally dehydrated, marketed as fertilizer; digested sludge, disposed on land or composted. Methane from digestion used as fuel for drying.
c) combination-raw sludge, incinerated; digested sludge, disposed on land or composted. Methane from digestion used as fuel for incineration.
d) raw sludge-incinerated; digested sludge, thermally dehydrated, marketed as fertilizer, using methane as fuel for drying.
e) raw sludge-incinerated.

We have not yet decided on which option to choose. Full evaluation of the thermal dehydration process and marketability of the product is necessary. Another winter's operation on composting should fully describe design and operational parameters. The distribution of the compost must be defined as to what quantities the Washington Metropolitan Area can absorb.

In the fall of 1974, the EPA-DC Pilot Plant will start work on a unique system for sludge disposal. The system will incorporate the best aspects of anaerobic digestion and thermal dehydration and make the two processes more compatible. Methane gas produced by high rate digestion is of sufficient quantity to totally dry the residual sludge after vacuum filtration. The problem with digestion is that the process converts a large portion of the insoluble organic nitrogen to soluble ammonia, and the residual sludge contains only 2.5 - 3.0 percent nitrogen, which limits its marketability. The pilot scale process will separately treat the digester supernatant to recover the ammonia as a crystallized ammonium salt, which can be used to upgrade the total nitrogen content of the dried sludge. The process includes raising the pH of the supernatant stream, air stripping to remove the ammonia and then recapturing the ammonia by contact with sulfuric acid. The resultant ammonium sulfate is recirculated to build up the concentration and a sidestream run to a crystallizer. The solid ammonium sulfate will be blended with the dried sludge.

In general, because of the energy situation, we are looking closer at the digestion process, and the use of the resultant methane as a resource. Methane for drying or incineration is especially attractive economically. We are even now running a project to operate a motor vehicle with purified sludge gas.

In summary, we are desperately attempting to define a permanent solution to the sludge disposal problem. With each apparent solution, there appears a new stumbling block and always more information is required. We only wish that the technology of sludge disposal could be as well-defined as the technology of wastewater treatment and air pollution control. Some of the efforts at Blue Plains will hopefully define some solutions.

NOMENCLATURE

BOD_5	five-day biological oxygen demand
MGD	million gallons per day
mg/kg	milligrams per kilogram on a dry weight basis
mg/l	milligrams per liter

AGRICULTURAL UTILIZATION OF DIGESTED SLUDGES FROM THE CITY OF PENSACOLA

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The concept of turning a liability into a profit is becoming a reality for Pensacola, Florida. Before 1974, the daily load of 80 to 90,000 gallons of digested liquid sewage sludge from the Pensacola Main Street Sewage Treatment Plant was not only a useless noxious material, the city had to truck the sludge 18 miles and pay to dump it in the county sanitary landfill. In late 1973, the County Commission of Escambia County Florida and the City Council of Pensacola through the Intergovernmental Program Office agreed to share the costs of a one year experiment to determine the feasibility of using liquid digested sludge for agricultural production on deep sandy coastal plains soils. The project unites efforts of the University of Florida and the University of Florida Agricultural Research Center near Jay, Florida, the University of West Florida, the Florida Department of Pollution Control, the Florida Department of Health and Baseline, Inc. (a private consulting firm). The ultimate goal of the project is to establish safe procedures for deposition of 80,000 gallons per day of sludge produced at the Pensacola Main Street Sewage Treatment Plant.

Now at the end of April, 1974, an average of 30,000 gallons per day of liquid digested sludge is being applied to crops at the Agricultural Research Center near Jay, Florida. The composition of the sludge from the Main Street Plant is presented in Table 1 in parts per million and in Table 2 as pounds per acre inch.

Experimental design is based on greenhouse experiments at the University of West Florida and the ARC Jay, Florida under the direction of Dr. Joe A. Edmisten. Edmisten's greenhouse experiments were designed to establish the rates of sludge application that could be tolerated by tomatoes, corn and a variety of horticultural materials. The liquid sludge was applied to the potted corn and

TABLE 1
Elemental Composition of Pensacola's Liquid Digested Sludge

Element	*mg/liter(ppm)*[1]	*mg/kg(ppm)*	*(Dm basis)*[2]
Calcium	60.0	1,764.7	(0.18%)
Magnesium	17.0	500.0	(0.05%)
Potassium	30.0	882.4	(0.09%)
Phosphorus	12.0	352.9	(0.04%)
Aluminum	400.0	11,764.7	(1.18%)
Iron	166.0	4,882.4	(0.49%)
Manganese	1.8	52.9	
Copper	3.9	114.7	
Zinc	120.0	3,529.4	(0.35%)
Sodium	85.0	2,500.0	(0.25%)
Chromium	4.3	126.5	
Lead	0.5	14.7	
Silicon	264.0	7,764.7	(0.78%)
Titanium	0.0	0.0	
Nickel	3.0	88.2	
Mercury	0.024	0.7	
Cobalt	0.8	23.5	
Cadmium	0.011	0.3	
Lithium	0.014	0.4	
Boron	--	--	
Arsenic	--	--	
Selenium	--	--	
Molybdenum	--	--	
Nitrogen	1,787.0 (0.18%)	52,558.8	(5.26%)

[1]Wet basis—the liquid digested sludge sample contained 96.6 percent water (3.4 percent solids).
[2]Dry matter basis.

TABLE 2
Analysis of Pensacola's Sludge Taken in Early 1973

Sample Taken	*Elements in pounds/acre*														
	Ca	*Mg*	*K*	*P*	*Al*	*Fe*	*Mn*	*Cu*	*Zn*	*Na*	*Cr*	*Pb*	*Si*	*Ti*	*Ni*
1/29/73	183	14	6	3	98	35	0.7	3	28	11	3	3	60	0	0.2
2/5/73	122	10	6	3	69	30	0.6	2	23	11	2	2	51	0	0.2
2/21/73	204	16	9	2	105	37	0.7	3	29	11	3	3	65	0	0.3
Average	107	13	7	3	91	34	0.7	3	27	11	3	3	59	0	0.2

Previous analyses indicate about 200-300 lbs. of nitrogen per acre inch of sludge.
A six inch column of sand removes about 95 percent of the BOD.
Corn yields were increased from 96-118 bu/acre using 4.7 acre inches of sludge on a previously well fertilized area.

tomatoes at rates of zero, two, four and eight inches per week. At the end of the experiment, composition of the plants was ascertained as to total nitrogen (Table 3), zinc, copper and manganese (Tables 4 and 5). The application rates of four and eight inches per week were found to drown plants and were discontinued. While the plants could tolerate up to two inches per week, the optimum rate of application was established at about one inch per week. Analysis of plant tissues indicated that accumulations of heavy metals such as zinc and/or copper could be expected. Edmisten's and Lutrick's greenhouse work forms the basis for rates of sludge applications in the field experiments now in progress on the ARC farm.

The field experiments are being conducted under the direction of Dr. Monroe Lutrick of the ARC, Jay, Florida. Specific goals of the project include the following:

1. Three experiments, having four replications each, with treatments of 0, 3, 6, 9, 12 and 15 acre inches of sludge per year will be established. Applications of the liquid digested sludge will be made prior to planting on an annual basis. Corn, sorghum and soybeans will be the three crops used. Soil samples will be taken to 24-inch depths at 6-inch intervals prior to sludge application. Soil and plant samples will be taken for analyses when the plants are in early anthesis. Grain and soil samples will be taken when the grain is mature.
2. A similar experiment will be applied on pine timber land that has been chopped and is in various stages of regrowth.
3. A large depression will be filled with the liquid digested sludge to determine if the material can be stored without leakage for later distribution on agricultural lands.

TABLE 3
Average Nitrogen Content of Tomato and Corn Leaves in Percent Dry Weight Grown on Sludge in Greenhouse Experiments

Treatment	*Tomatoes % N in leaf*	*Corn % N in leaf*
½ inch/week	1.6	1.7
1 inch/week	1.9	2.1
2 inch/week	2.2	--
2 inch/week	died	--
controls	1.5	1.6

TABLE 4
Micronutrient Content Averages of Tomato Leaves Grown on Sludge in Greenhouse Experiments

Treatment	*Mn ppm*	*Cu ppm*	*Zn ppm*
1 inch/week	105	31	614
2 inch/week	120	38	666
4 inch/week*	110	40	717
controls	18	8	508

*This heavy application killed plants after two-three weeks.

TABLE 5
Micronutrient Content Averages of Corn Leaves Grown on Sludge in Greenhouse Experiments

Treatment	*Mn ppm*	*Cu ppm*	*Zn ppm*
1 inch/week	90	40	660
½ inch/week	60	18	590
controls	20	12	420

4. In order to determine if there are accumulations of the heavy metals or certain microorganisms in tissues (liver, blood, muscle, fat, etc.) of steers grazing pasture grasses which have been fertilized with liquid digested sludge, two groups of steers will be fed in drylot for approximately six months and slaughtered. One group of steers will be fed the dry ration without any dried sludge while the dry ration of the other group will contain approximately five percent dried sludge. Animal tissues will be collected and examined for pathological lesions and for heavy metal and microbiological assays.

After many false starts and hesitations due to difficulty in obtaining key pieces of equipment, the experimental project is now in full swing. As of mid-May an average of five tanker loads of sludge per day were being hauled to the experimental fields. Each tanker load is about 6,000 gallons resulting in the 30,000 gallons/day figure. On days when the soils are too wet to allow the direct application of sludge to the soil, the tankers are unloaded into the holding lagoon (Figure 1) located in a depression on the farm.

Figure 1: A Dock Can Be Seen Protruding into the Sludge Lagoon. Along this Dock Are Located Water Sampling Tubes Designed to Sample Surface Soil Water from Depths Varying from One to Twelve Feet Deep.

Normally the 6,000 gallon tanker is unloaded directly into the 3,000 gallon liquid manure spreader. The special transfer pump will unload one half of the 6,000 gallons in about ten minutes (Figure 2). The spreader, pulled by a large Ford tractor leased for the one year experiment, is very effective and accurate in the application of the sludge to bare ground as well as plots already having plants (Figure 3). Average time to get to the field plots, apply the fertilizer and return for the second load to empty the tanker is 14 minutes.

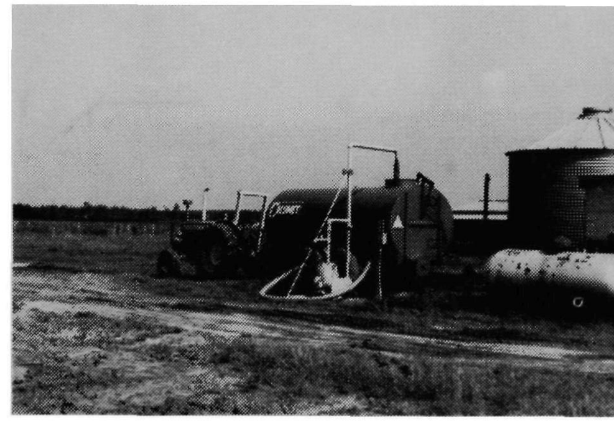

Figure 2: Much of the Delay in Getting the Sludge Project Going Centered Around These Machines. The Liquid Manure Spreader Cost $5,200 and had to be Escorted to Pensacola. The Transfer Pump with Accessories Cost $1,135. The Pump Functions at a Rate of 300 Gallons Per Minute and will thus Load the 3000 Gallon Spreader in Ten Minutes. The Large Ford Tractor Needed to Pull the Spreader Is Valued at $10,000 and Is Leased with IPO Funds for $1,500 Per Year.

The field plots on which the sludge is being applied at various rates are 120 by 40 feet in size. The 40 foot width is ideal for the designed "throw" of the spreader so it moves at a moderate pace between the plots (Figure 4). From the field plot diagram (Figure 5) distribution, crop and treatment can be seen. Three crops will be grown in the experiment, corn, sorghum and soybeans. Each crop will have 24 plots in which four will receive no sludge, four receive three inches, four receive six inches and so on through 9, 12 and 15 inches for the growing season.

Various tests for groundwater contamination, accumulation of toxic heavy metals, bacterial contamination of soil, water and animals are being regularly completed. In Figure 6 one can see the top of a 70 foot deep well near the test holding lagoon from which water will be taken at regular intervals for such tests. In the right background of Figure 1, one can see a pier built out into the sludge holding lagoon. The pier gives access to water sampling devices from which water can be taken from the soil directly below and in the holding lagoon at depths of one to twelve feet.

Similar deep wells and shallow soil water samples are located in and around the 72 field test plots presented in Figure 5.

Other precautionary tests included in the experiments are regular testing of surface and subsurface soils for fecal coliform bacteria. In Figure 7, Dr. Lutrick is shown collecting these soils for microbiological tests which are being performed by

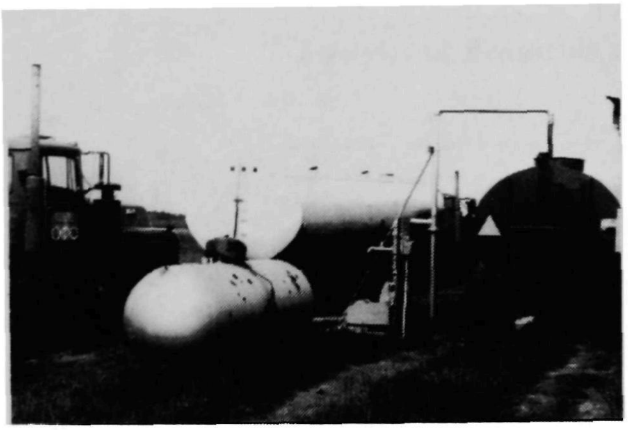

Figure 3: A Large Part of the $80,000 Funding of the Project went to Buy a New Tanker to Transport the Liquid Sludge to the Experimental Farm. Here One 6000 Gallon Tanker Is Unloading While Another Waits the 28 Minutes Needed to Spread the Two 3000 Gallon Loads with the Spreader. It Takes the Spreader Five Minutes to the Field, Four Minutes to Spread the 3000 Gallons and Another Five Minutes to Return to the Tanker.

Figure 4: The Liquid Manure Spreader Is Shown in Action. It Is Designed to Spread at 750 Gallons Per Minute and Throws the Material Evenly Over a 40 Foot Area to Its Left. Here a Low Area Is Being Covered Several Times Before Planting. In Front of It Are Patches of Corn That Were Planted in Areas Previously Treated Which Will Continue to Receive Sludge Up to a Prescribed Level. The Treatments Vary from Up Through 3, 6, 9 and 12 Inches of Sludge for the Growing Season.

the regional laboratory of the Florida Department of Health to determine the fate of human fecal bacteria in the sludge, soils, plants and groundwater.

Further precautions that bacterial hazards will not be produced by this agricultural utilization of sludge are seen in the sub-experiment in which dried sludge is fed to test animals. Six steers (Figure 8) were bought for this experiment. Three of the steers are being fed 100 grams of dried sludge in their daily ration. The other three serve as controls and receive no sludge. The six steers will be slaughtered after six months and their tissues will be carefully tested for bacterial and/or heavy metal contamination. During the feeding experiment the six test animals will be monitored as to growth, behavior and general response to the ingestion of the 100 grams of dried sludge which approximates the daily consumption of one gallon of the fresh liquid sludge.

Greenhouse experiments continue and are designed to further test the effect of sludge on the growth of corn and to ascertain if the water leached from the experiment will contaminate the soil water. In Figure 9, one set of plants is shown from an entire set in which soils of the Troup and Red Bay series have been placed in large cylinders. Water from sludge applied to the top of the cylinder is collected at the bottom for chemical analysis of (NO_3) nitrate, (Cl) chlorides and (K) potassium. The differential growth rates associated with rates of sludge application will be noted in Figure 9 where the tube getting no sludge is on the right and the tubes getting 3, 6, 9, and 12 inches are progressively taller to the left.

40'

120'

3	6	0	15	9	12	0	3	6	9	12	15	CORN
15	9	12	3	0	6	12	15	6	9	3	0	
3	6	0	15	9	12	0	3	6	9	12	15	SORGHUM
15	9	12	3	0	6	12	15	6	9	3	0	
3	6	0	15	9	12	0	3	6	9	12	15	SOYBEAN
15	9	12	3	0	6	12	15	6	9	3	0	

inches of sludge applied: 0, 3, 6, 9, 12 and 15.

Figure 5: The Field Plot Diagram for Number, Distribution, Crop and Treatment with Pensacola's Sewerage Sludge.

Figure 6: Several Deep Wells Have Been Drilled to Depths of up to 70 Feet at Key Sites In and Around the Experimental Areas. Here a Well is Shown Near a Sludge Holding Lagoon. Water will Be Drawn from this and Other Wells at Regular Intervals and Be Tested for Bacteria, Nutrients and Toxic Heavy Metals.

Figure 7: Dr. Lutrick Collecting Soils for Microbiological Tests.

The sludge research project has fired the energy and imagination of the entire staff and faculty of the experiment station. Almost all of the senior faculty members of the experiment station are involved in the experiment in some way. The station nematologist hopes that the accumulation of organic matter will allow a significant (½) cut in the amounts of nematocides needed to control cyst nematodes, a serious pest on soybeans. There is a series of small test plots in which a wide variety of grasses and other crops are being grown with varying rates of sludge applications. No results are available from these test plots at this time but the crop responses to sludge appear to be in keeping with earlier greenhouse experiments in which yield increases are proportional to sludge applications up to the point of flooding.

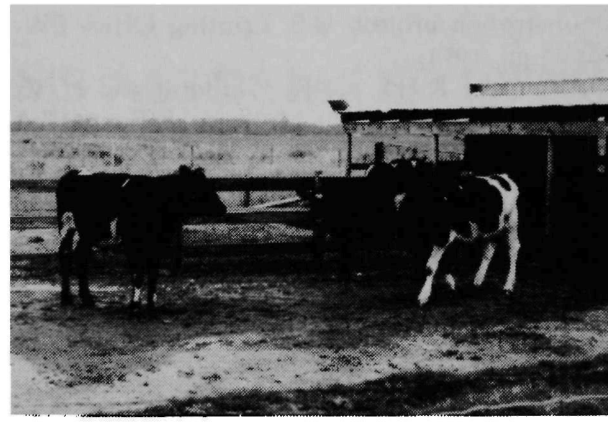

Figure 8: Six Young Steers Were Purchased at a Price of $886.49 as a Part of the Experiment. Dr. Bertrand Is Currently Feeding Three of the Six a Sludge Supplement of 100 Grams Each Day to Test the Theory that Animals Might Be Harmed by the Direct Consumption of the Dried Sludge from Grass to which It Has Been Applied. So Far in Two Months of Feeding the Three Test Steers Are Doing as Well or Better Than the Three Control Steers. The Food with 100 Grams of Added Sludge Is Consumed Readily by the Test Animals.

Figure 9: The Greenhouse Experiments Started by Dr. Edmisten at the University of West Florida, Pensacola, Florida are Continued at the Jay, Florida Station. Here Dr. Lutrick Grows Corn in Cylinders of Two Soil Types, Red Bay and Troup. Sludge Is Being Applied at Rates of 0, 3, 6, 9 and 12 Inches Total from the Right to the Left. Liquids from These Applications Are Collected at the Bottoms of the Cylinders and Are Tested for NO_3, K and Chlorides.

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INSTITUTIONAL PROBLEMS ASSOCIATED WITH SLUDGE DISPOSAL

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ABSTRACT

The institutional problems of sludge disposal are a result of the opinions and attitudes of the public which are translated into political policy and regulation. Incineration was chosen as the method of sludge handling at the Piscataway (Md.) Wastewater Treatment Plant in a 1970 engineering study for the Washington Suburban Sanitary Commission (WSSC). However, citizen allegations that incinerator test operations had caused high blood lead levels in area children resulted in a County Council resolution to temporarily halt incineration at Piscataway. Despite County Health Officer and EPA findings that there was no evidence of a health hazard at Piscataway, a second resolution was passed that terminated incineration until EPA standards were established and there was a conclusive determination that no health hazard would exist in the Piscataway area.

This decision will seriously affect the WSSC sludge disposal program and could cost millions of dollars. It also implies that institutional problems are expected to increase across the nation with growing citizen awareness and activity.

INTRODUCTION

Sludge treatment and disposal is rapidly becoming the most sophisticated and costly portion of sewage treatment in many municipal plants, often accounting for more than half of the capital and operating costs of treatment. The increasing quantities and types of municipal sludge, along with the numerous combinations of treatment and disposal alternatives, present major engineering and management problems both in design and operation of treatment plants. Although the engineer's application of available technology can lead to decisions on these problems, much more attention must be given to improving existing techniques and the development of new technology. However, while this improved technology will lead to more effective decisions on treatment and disposal, the institutional problems associated with sludge disposal are increasing in scope and magnitude to a position of overriding importance to the technical selection of a most "cost-effective" alternative in many areas.

An institution, as used here, is defined as a significant and persistent concept in the life of a society that centers on a fundamental human need, activity, or value, and is usually maintained and stabilized through social regulatory agencies. Institutional problems can be considered to originate from the social-political-aesthetic values, often referred to as the intangible aspects of engineering analyses, which are translated into public utility policy and regulation.

The role of decision making on many sludge related problems today often rests on the cumulative expressed attitudes of the public being affected by those problems and decisions. This public, increasingly, is selecting sludge disposal methods and approaches which do not represent monetary or technical considerations. Rather, they are making decisions based on their view of the relationship these disposal methods have with the environment in which they live. It is these subjective public opinions and values that form the basis of the institutional problems of sludge disposal which seem to be a major source of frustration and difficulty to many officials involved with municipal sludge management.

The Piscataway Problem

Institutional problems have particularly plagued the Washington Suburban Sanitary Commission in recent years. Established by the Maryland State Legislature in 1918, the WSSC provides water and sewer service to Montgomery and Prince George's counties, which make up the Maryland portion of the suburban area surrounding Washington, D.C. Extremely rapid population rise of the suburban Washington area in the last 15 years has resulted in numerous growth problems, particularly for public service agencies. This area is also highly politicized as a result of its proximity to the Federal Government enclave. It is marked by many moderate and upper-income, well-established neighborhoods maintaining strong, active local citizen associations. These citizen groups exert considerable political pressure in the several local jurisdictions the WSSC serves.

There is an abundance of public and political agencies dealing with planning and environmental problems on both a local and regional level. These numerous agencies and local governments have created a proliferation of opinions on what is the best method of handling sewage treatment and the sludge generated from that treatment. Therefore, attempts at regional cooperation have been marked by bitter political battles and court suits. At the same time, many of these agencies have a direct influence or control over the WSSC.

Until 1967, almost all of the sewage generated within the Sanitary District was treated at the regional Blue Plains Sewage Treatment Plant in Washington, D.C. At that time, the WSSC began a program of construction which has resulted in three major treatment facilities. All three facilities are undergoing expansion and upgrading to advanced waste treatment and will have a combined capacity of almost 70 mgd by 1976.

The plant at Piscataway, ten miles south of Washington, D.C., was built in 1967 with a capacity of 5 mgd. It serves the southern Prince George's County area which is currently undergoing rapid growth, following the pattern of the rest of the D.C. area. The Piscataway area is characterized as a rather exclusive neighborhood by its residents who would prefer to restrict growth to maintain the area's present quality. The plant effluent is discharged to Piscataway Bay on the Potomac River while the sludge undergoes anaerobic digestion, vacuum filtration, and then landfill or land spreading. Since 1967, the plant has been expanded in stages to its present capacity of 30 mgd, with fluidized-bed incineration facilities the phase just being completed. The final phase of the expansion will be conversion of the anaerobic digesters to holding tanks to support the operation of the incinerators. Currently under design are facilities to upgrade the 30 mgd secondary plant to advanced waste treatment for removal of phosphorus, nitrogen, and residual solids.

The decision to utilize incineration for sludge disposal at Piscataway was based on a 1970 engineering study on sludge management for all WSSC sewage treatment facilities[2]. This study was undertaken by the WSSC to determine the most feasible and economical method of sludge treatment and disposal for the three existing, and one proposed, plants through the year 2000. At that time, the general uncertainty surrounding the use and acceptance of county controlled landfills for sludge disposal led to the conclusion that the "WSSC should adopt a sludge management concept that would provide maximum flexibility and control of the situation, even under adverse conditions. Such a concept is sludge combustion." The concluding recommendation of the study was that sludge incineration should be implemented as the most "cost-effective" solution at all the plants. With the decision to build incinerators came the corresponding action to utilize the existing anaerobic digesters as sludge holding and blending tanks. Although there was substantial redundancy with a standby incinerator, we were thus left with no alternative method of treating raw sludge for land disposal.

However, in 1970, all indications were that incineration would be the best method of future disposal, particularly for densely populated metropolitan areas. This view was reinforced by Federal, State and local health and environmental agencies. In fact, in early 1974, state and local health departments reinforced the opinion that incineration was the preferable method of sludge disposal for the suburban D.C. area. There was no foreseeable need for any sludge treatment process other than incineration.

Meanwhile, there had been slowly growing opposition to expansion, and the associated incineration, of the Piscataway Plant by area citizen groups. The WSSC recognized this citizen opposition as well as the unanswered questions about sewage sludge incineration, and in the summer of 1973 initiated a contract with Battelle-Columbus Laboratories to perform an impact analysis on the operation of the fluidized-bed incinerators at

Piscataway[3]. The study would involve analyzing all incinerator process streams for all possible detrimental components—particulates, vapors, aerosols and trace metals. This data would then be evaluated in light of existing standards as well as pertinent supportive or refutive data where existing standards were questionable, or areas not identified by existing or proposed standards.

This impact analysis was further expanded to include ambient and environmental analyses, to be performed by the University of Maryland. This data on present and historical conditions in the Piscataway area would provide a better basis from which to evaluate the impact of the incineration operation. However, by early 1974, citizen opposition was gaining in strength and momentum and becoming more vocal. The fluidized bed incinerators at Piscataway were nearing completion and had operated about 70 hours for curing and startup testing when, in late March, two area families claimed that the incinerator operation at Piscataway had caused high levels of lead in the blood of their children. The citizens carried their case to the Prince George's County Council who immediately passed a resolution which prohibited incineration at Piscataway until the cause of the high blood lead levels was determined by the County Health Officer. The County Council resolution was further reinforced by a telegram from Region III, EPA Headquarters halting incineration until it could be determined no health hazard existed.

As a result, the County Health Officer performed nearly 200 blood tests on area children within ten miles of the Piscataway Plant as well as testing all 80 plant personnel. Of all the tests performed for lead, all levels were normal except for one plant operator who apparently had an abnormality in his blood from an as yet unknown cause. The children who originally had high lead levels were retested twice and found to have normal blood lead levels both times. In addition, environmental tests by the Prince George's County Health Department showed no elevated lead levels in the air or soil near the plant. The Health Officer concluded that the incinerators posed no significant health hazard and there was potentially more danger of increased lead levels in the Piscataway environment from auto exhaust emissions.

During the brief period of incinerator testing at Piscataway, engineers from the EPA Standards Development Branch in North Carolina were able to obtain a stack gas sample. This work was performed as part of their larger effort to obtain data for the establishment of sewage sludge incinerator stack emission standards for the nation. These were the only tests that were allowed to be performed on the incinerators before the operation was halted. Although only preliminary data is available from these tests, the maximum lead quantity that would be emitted from the incinerator stacks at a sludge loading rate of about 5,000 pounds per hour was found to be four grams per day.

The Piscataway area citizens had introduced to the County Council a new resolution which would halt incineration at Piscataway until establishment of EPA standards on sludge incinerator stack emissions and a conclusive determination that the sludge burning would pose no health hazard to the particular topography of the area. On April 28, this resolution was brought before the Prince George's County Council. The findings of the County Health Officer, and the EPA Standards Development Branch data were presented along with the WSSC request to allow the incinerators to be operated to conduct the Battelle/University of Maryland stack emission studies to determine if a health hazard did exist. The EPA had rescinded their earlier restriction and recommended incinerator operation be allowed in order to conduct the proposed tests.

The Piscataway area citizens argued against any operation of the incinerators in that there was a possible health hazard which could not be absolutely refuted. They did not want to be used as "guinea pigs" for incinerator tests considering the many questions about the alleged dangers of stack emissions that could not be answered.

The resolution to halt incineration passed the Prince George's County Council unanimously. Implicit with this resolution was that incineration of sewage sludge in Prince George's County was an unacceptable alternative until it was conclusively proven no public health hazard would exist. Thus, the cumulative opinion of private citizens on the real or imagined dangers of incineration had been successfully translated into public law. This institutional decision had no apparent relation to technical or economic feasibility, but rather was based almost exclusively on the attitudes of those citizens in the area affected by the sludge treatment and disposal.

CONCLUSION

Unfortunately, much of the public maintains preconceived ideas about sewage sludge and the associated disposal techniques. These ideas may be based on hearsay, false or inaccurate reports, and experience with poorly designed or operated disposal facilities. However, for whatever underlying reasons, it is public opinion which often influences and forms policies which affect sludge management. The institutional problems of sludge disposal are thus a result of the subjective values of the different sectors of the public being affected by the disposal.

Because different public and private groups and agencies have different, constantly changing preferences and values on environmental quality, they exert differing pressures on municipal agencies. A sludge management decision acceptable today may not be socially or politically acceptable two or three years from now. Also, as public awareness and concern for the quality of the environment in which they wish to live grows, this awareness will increasingly reflect itself in public attitude and political decisions under which the public utility must operate. Therefore, the institutional problems associated with sludge disposal should be expected to increase across the nation.

The Piscataway situation is an institutional problem which will obviously have a serious impact on the WSSC sludge disposal program. If the incinerators cannot be operated, the Battelle/University of Maryland studies on the incinerator impact cannot be performed. Without these tests, it would be highly doubtful if the potential health hazard of incineration could be conclusively proven or disproven at Piscataway. It also affects the two other major WSSC plants where incinerators are under construction. The costs of this institutional decision to restrict sewage sludge incineration in Prince George's County could be millions of dollars for facilities already constructed and replacement facilities.

If institutional problems are expected to increase and introduce potentially high economic risk for sludge management decisions, what can be done to reduce the impact of such problems? In the past, there has often been a lack of understanding and a resultant lack of consideration by officials in public utilities and regulatory agencies of the social-political values associated with sludge disposal. Analysis of sludge problems has tended to concentrate on those areas that are easily quantifiable; that is, capable of being expressed in readily measured units such as dollars or tons of solids.

Therefore, the most important consideration in reducing institutional problems will be recognition of public attitudes on sludge disposal. This requires maximum exposure of the public to sludge management decisions well in advance of their implementation. Full public participation in the preliminary planning stages of sludge disposal programs should be invited. The values and attitudes of citizens affected by the sludge disposal should then be weighed accordingly in any sludge management decision. Although such techniques may slow the decision process or seem to lead to an alternative that does not appear to be the most cost-effective, consideration of public values in the planning stages will minimize the impact of institutional problems after disposal methods are being developed or in operation. At the same time, exposure to the public provides the municipal utility the opportunity to educate the citizens on the true merits of various sludge disposal alternatives.

Because public attitudes are constantly changing and reflected in changing political regulations, municipal officials should recognize the economic risks that can be caused by institutional problems in selecting a single sludge treatment and disposal method. Careful consideration must be given to all alternatives in the initial planning stages and then narrowed to the several most feasible methods. The decision on the best alternative or combination of alternatives should be made with the commitment of appropriate political regulatory agencies and with full awareness of the affected public. The other feasible methods should be continuously evaluated in comparison with the original choice to insure the best disposal method is being utilized, as well as to provide a contingent sludge disposal method if needed.

Thus, while institutional problems of municipal sludge disposal are expected to increase, increased attention to public attitude and proper analysis of disposal alternatives by utility officials will result in a greatly reduced impact from these problems.

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ENERGY CONSERVATION AND RECYCLING PROGRAM OF THE METROPOLITAN SEWER BOARD OF THE TWIN CITIES AREA

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PURPOSE

The purpose of this report is to describe recent actions of the Metropolitan Sewer Board of the Twin Cities Area in meeting the energy crisis that engulfed the nation in 1973. As regional wastewater treatment authority for the seven-county area focusing on Saint Paul and Minneapolis, Minnesota, the Board operates all interceptors and the 24 treatment plants in the area.

ABSTRACT

The Board has instituted ten major programs oriented to process and operational changes in their major treatment plants relating primarily to energy saving and recycle, without diminishing the quality of treatment of wastewater. In addition, many minor improvements have been made in operations to conserve materials and energy sources. Among the major approaches are:

- Phyrolysis of municipal refuse to furnish heat value for sludge drying.
- Recovery and beneficial use of heat in exhaust gases from incinerators.
- Continuous pressure dewatering.
- Flameless odor control.
- Improved results by modifying existing sludge processing equipment.
- Manufacture of fuel-grade sludge cake and char.
- Preparation of fertilizer, soil conditioner and recyclable metal scrap.
- Use of solid fossil fuel . . . coal . . . to augment combustion in incinerator furnaces.
- Manufacture of activated carbon for in-plant use.
- Pulping of refuse fibers for use as filter aid.

Population Involved

In serving a population of almost two million people, the Metropolitan Sewer Board is serving one of the more environmentally aware and ecologically motivated populations in the country. Past events such as concern for preservation of wilderness areas in the state, avoiding potential hazards from industrial and public utility operations, and active citizen involvement in the political process have made the Twin Cities Area a significant focal point for environmental concerns. Thus, in analyzing present operations and proposing expansions that are more conservative energy-wise and material-wise, the Metropolitan Sewer Board is working in behalf of interested citizens who comprise half the population of the State of Minnesota.

Urgency

Although finding of alternatives to usual fuels is critical at this time because of demonstrated shortages, the Chairman of the Metropolitan Sewer Board had urged consideration of alternatives as long ago as 1970, at which time the likelihood of shrinking supply of fossil fuels became apparent.

This concern was certainly well justified. In July of 1973 the Metropolitan Sewer Board opened bids on fuel oil supply for the coming operating year. Of seven responding suppliers, none offered a contractual bid on the Board's fuel requirements of 3.4 million gallons.

This proved to be the first indicator of the seriousness of the problem. At that time the Board expedited the finalizing of plans and specifications for supplemental oil storage capacity that would allow handling of heavier oils than the present system can accommodate and also commenced a series of discussions within the staff on what could be done in all ways to reduce fuel usage. Economy of operational equipment and emergency steps that might have to be taken in the event the fuel supply was cut off were considered.

As was well documented a few months later, changes in the world supply of oil products precipitated a drastic price rise (Figure 1) and also a shortage which caused the Board to have serious concern about maintaining full treatment of the wastewater during the winter months. Costs rose from 92 cents per million Btu to a peak of $2.30 per million Btu, settling back to a present figure of $2.15 per million Btu. Fortunately, building heating requirements proved moderate in this past winter and as a result we did not have to interrupt the high level of treatment because of supply.

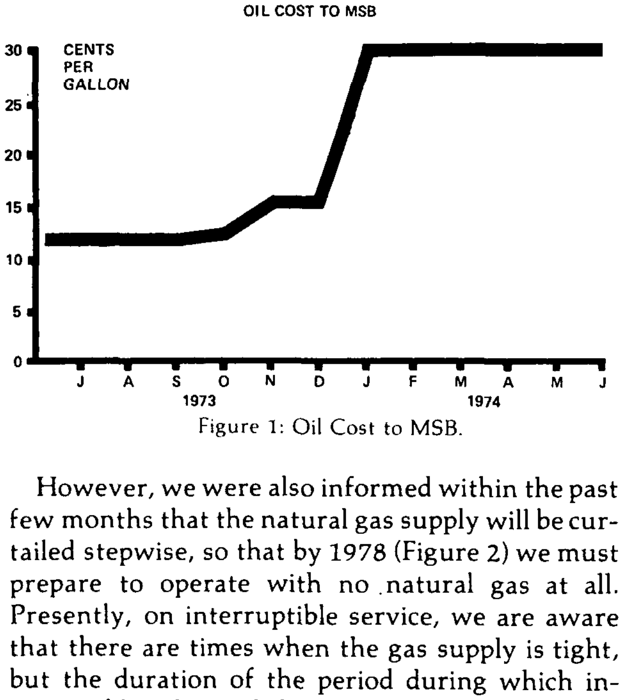

Figure 1: Oil Cost to MSB.

However, we were also informed within the past few months that the natural gas supply will be curtailed stepwise, so that by 1978 (Figure 2) we must prepare to operate with no natural gas at all. Presently, on interruptible service, we are aware that there are times when the gas supply is tight, but the duration of the period during which interruptible rules apply has been increased. Gas is no longer going to be available as the preferred low-priced, high-grade fuel, for the relatively mundane task of drying water out of sludge in order to make it combustible.

A second point in the urgency pattern is the pressure by the regulatory agencies, both federal and state, that we comply with the public will for higher grade wastewater treatment. This calls for adoption of technology for wastewater treatment that has the end result of producing larger amounts of sludge, and more troublesome, sludges that are

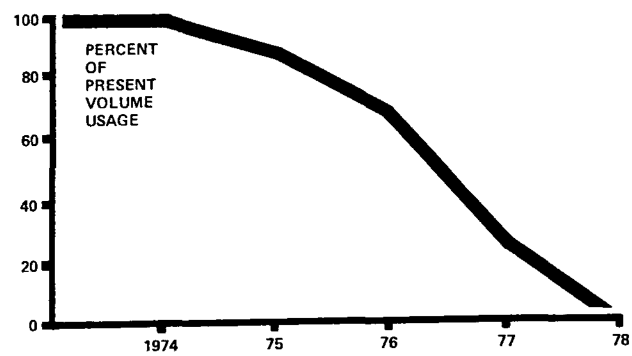

Figure 2: Natural Gas Supply Cutoff.

more difficult to dewater. We see more of the same coming in the future, because of the Federal requirements calling for "best practicable technology" to be in effect by mid-1983. We estimate that adopting presently known technology would raise our energy consumption by *fourfold* at least.

Another factor of concern and urgency is that alternatives to using more of present fuels have long lead times, including engineering, bidding, construction, and start-up. Typically, for systems of this type, the usual span is three to five years from the start of initial engineering to turning the system over to the owner.

For example, one of the more attractive and interesting possibilities is pyrolysis of a thermally balanced mixture (Figure 3) of sludge cake with other combustible matter, such as shredded refuse from domestic and commercial sources in the community. This system will be somewhat more complex than present combustion of sludge in the multiple hearth incinerators now in use, and will require some consideration of the performance levels that must be achieved in order for the process to be considered a satisfactory technical and economic success.

Another way in which energy can be conserved is by heat recovery from the incineration gases. This seems simple at first glance, but will require major modifications to the existing (Figure 4) furnaces and expansion of the building to house the heat recovery boilers and the necessary ducting and control systems. Presently, we quench the excess heat in the furnace gases by spraying water into the ducting before the scrubbers, and reduce the temperature by evaporating the water spray, from a temperature of around 800° F to 200° F. This temperature reduction is in effect a wastage of 1 billion 400 million Btu on a daily basis, or the net energy equivalent of 15,000 gallons of fuel oil.

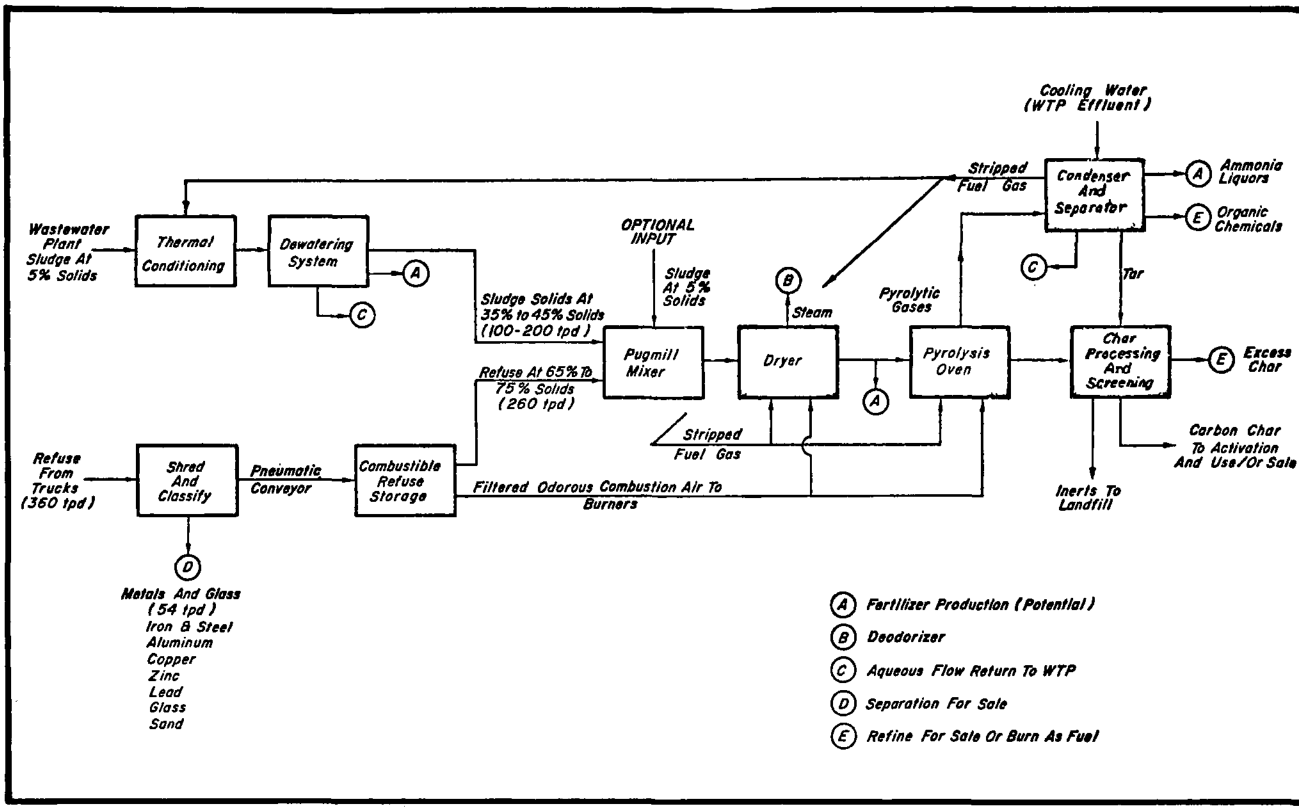

Figure 3: Flow Sheet for Demonstration of Combined Disposal of Sludge and Refuse.

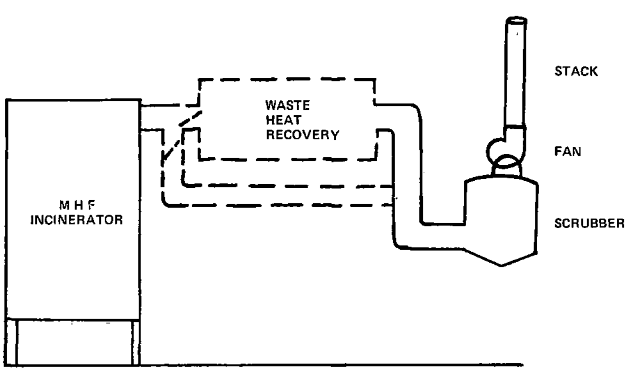

Figure 4: Installation of Waste Heat Recovery and Control Bypass In Between Breeching of Furnace and Scrubber Assemble.

It is known that, for heat recovery from sludge incinerators to be operationally practical, the temperature must actually be raised higher than present operating practice of 800° F, to perhaps 1200° or slightly more. This latter temperature is compatible with recent Minnesota Pollution Control Agency regulations that require 1200° F or equivalent for gas deodorizing, so by operating in this way we will comply and also eliminate the problem of ash residues depositing on heat exchange surfaces that can occur when temperatures are under 1100°.

Another alternative that can be considered as a technically viable approach is digestion of the sludge instead of thermal oxidation. This method has a long history of both successes and troubles in wastewater plants around the country, and is a substantial design challenge within the limits of the site that the main Metropolitan Plant occupies. It has the advantage, of course, of producing a stable soil conditioning residue and an excess of combustible gases that can be used for other beneficial purposes such as running compressors within the plant or operating vehicles. However ultimate disposal on this magnitude poses a real problem. We would need almost an entire rural township for adequate operation of land disposal.

The final point of urgency is that we now have plant expansion design under way for the main Metro plant. The decisions on technology changes must be made now so that the effect on the expanded capacity will be accomplished.

Legislative Direction

The Metropolitan Sewer Board has been stimulated in its consideration of conservation measures and recycling approaches by the wording in Public Law 92-500, The Water Pollution Control Act (Figure 5) Amendments of 1972. This legislation encourages the integration of wastewater

TITLE II

Sec. 201 Congressional Record, September 28, 1972 H8865

(d) "The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for--

(1) the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;

(2) the confined and contained disposal of pollutants not recycled;

(3) the reclamation of wastewater; and

(4) the ultimate disposal of sludge in a manner that will not result in environmental hazards."

(e) "The Administrator shall encourage waste treatment management which results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges. Such integrated facilities shall be designed and operated to produce revenues in excess of capital and operation and maintenance costs and such revenues shall be used by the designated regional management agency to aid in financing other environmental improvement programs."

(f) "The Administrator shall encourage waste treatment management which combines open space and recreational considerations with such management."

Figure 5: Excerpts from Federal Water Pollution Control Act Amendments of 1972.

treatment processes with other urban waste handling and also encourages generation of profitable products that can be derived from the waste. Early in 1973, the Minnesota Legislature passed an amendment to the Metropolitan Area legislation to enable us to comply with this act, thereby endorsing it as a state objective. Finally, in the most recent session of the legislature, the name of Metropolitan Waste Control Commission, effective January 1, 1975. Once again, this indicates the legislative intent that the Sewer Board broaden its scope of activity and encompass the treatment of solid waste materials as well.

Alternatives

A number of alternative fuels could be considered in substitution for the fossil fuels presently used:

1. The combustible fraction of municipal refuse.
2. Heavier oils, that might be in greater supply although more difficult to burn.
3. Coal, and lower grades of solid fuels such as lignite and peat which are found west and north of the Twin Cities.
4. Dried sludge, that has been brought to a point of being autogenous by thermal drying.
5. Wood chips from urban area tree trimming carried out by the city and county forestry departments and by utilities such as Northern States Power Company.
6. Industrial combustible wastes that are presently being disposed of in landfills.

Methods Chosen

The methods chosen in our program have as their overall objective that the Board's operations be as self-sufficient and thermally balanced as possible, with minimum use of electric power, and at the same time obtaining by-products that have value for use or sale. A desirable goal would be to minimize or eliminate the need to incinerate sludge cake in the future.

Each of the major plants was viewed as a site for improvements in technology. The following listing gives programs that are under way or planned for each. These are, of course, in addition to the normal housekeeping economies of removing excess light bulbs, turning down thermostats, and similar obvious energy conserving methods.

The Metropolitan Wastewater Treatment Plant, the "flagship of the fleet" is the most attractive area for energy conservation because it is the location where almost 90 percent of the wastewater generated in our area is treated. This plant has a present average daily flow rating of 218 mgd, and is now being expanded to a 290 mgd rating.

At this plant, the interesting projects are the following:

a. Pyrolysis of a mixture of sludge cake with shredded combustible refuse. This process, a novel approach to wastewater solids disposal, has the advantage of disposing of refuse simultaneously with the sludge. In the process of preparing the refuse, by shredding, the potential for recovery of metallic scrap is created. The process utilizes the gases and fuels developed in the pyrolytic oven to sustain itself, and therefore it does not require purchased fuel for operation. In addition, there is an output of char material, a fixed carbon, that has sufficient activation to be of interest for wastewater treatment in the main plant flow. This would then permit an in-plant use of a recycled material that will aid conformance to higher water quality requirements.
b. Another interesting project under design is a heat recovery system for recovering thermal energy from the burning of primary sludge. These heat recovery units would be fitted onto the existing furnaces. Hot flue gases are presently quenched with water sprays, thus wasting the heat as useless steam plume. We would be using the existing furnaces to the best advantage. The flow sheet for the use of this heat calls for a three-stage step down of the furnace off-gas, for maximum heat utilization. In the first stage, the gases (Figure 6)

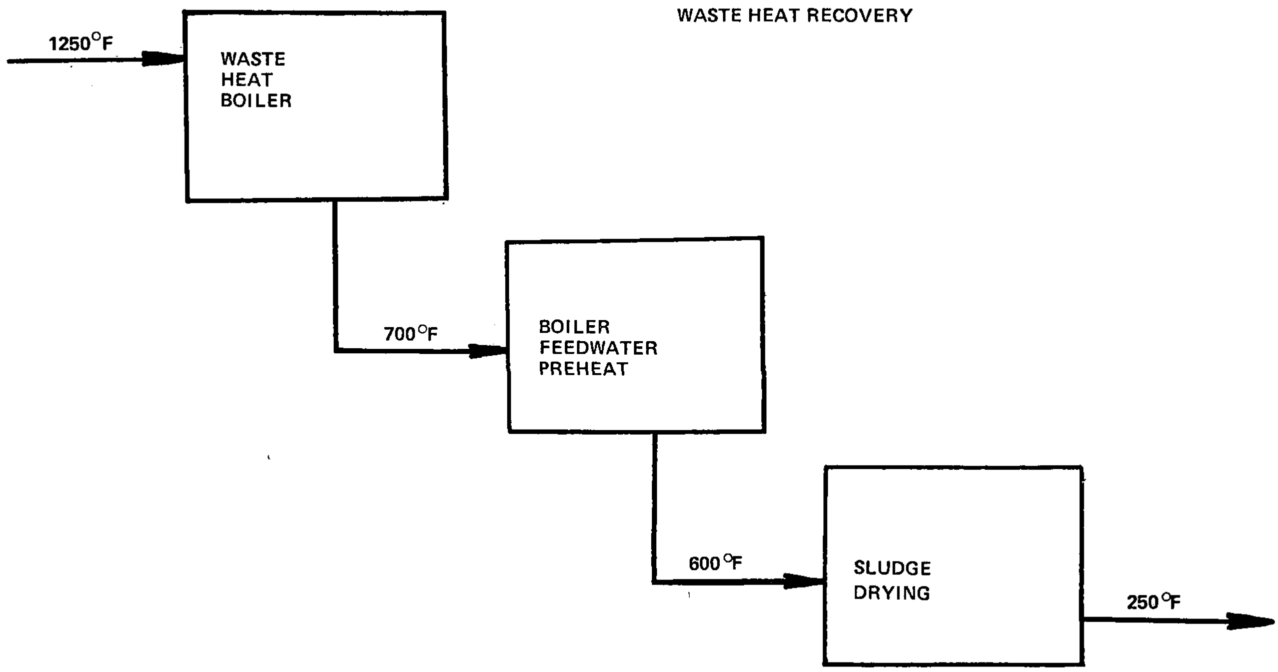

Figure 6: Waste Heat Recovery.

would be cooled from 1250° to 700° F in waste heat boilers capable of generating high pressure steam that can supply heat for the new thermal conditioning (heat treatment) of sludge, a process that improves dewaterability.

c. Another program of interest is just about to commence. This is an experiment with a roll press that has been used successfully in the paper and pulp industries for waste sludge dewatering. This press will be installed in the filter building at the Metro Plant and discharge cake to conveyors feeding the incinerators. By squeezing and developing a drier cake, the water burden carried to the furnace will be minimized and that way fuel consumption will be reduced or possibly eliminated. Pressure filters are the best way of accomplishing this, although there have been few outstandingly successful applications of pressure filters in municipal treatment plants in this country.

d. We also have great interest in determining the most efficient means of removing odors from off-gases. The obvious old standby is to use an afterburner as a means of destroying odors, most of which have a combustible nature. However, this is not always foolproof, and also is tremendously expensive in terms of fuel usage. We intend to experiment with a wet scrubber that uses chemical solutions, to determine its capability to absorb and retain odor factors in the gases produced by drying and burning sludge. This will then be the basis for a design decision in either direction for our major sludge drying facility that is now being planned.

e. Another area in which we have made significant improvements in the past year is in utilizing our existing gravity thickeners more effectively. In the past, it was the practice to blend a high ratio of raw waste activated sludge solids with primary sludge. Typical ratio was 70:30. We find it more effective to (1) use a much higher amount of primary solids, 50:50, thus lowering the ratio of biological solids, and (2) aerobically digest all waste activated sludge for a minimum of ten days. By allowing the overflow to return to the primary settling tank from which primary sludge is being drawn for this process, an "overload" condition can be tolerated. Even though a lot of input solids report in the overflow from the thickener, 20 to 50 percent, there is in effect a closed loop on the overflow (Figure 7) which retains the solids that are carried out. The applied rates, 20 to 30 pounds per square foot per day, would normally be unacceptable for a mixed sludge thickener, but such operation is satisfactory to us, provided that the biological solids are aerobically digested. This process maintains a more dense underflow, in the

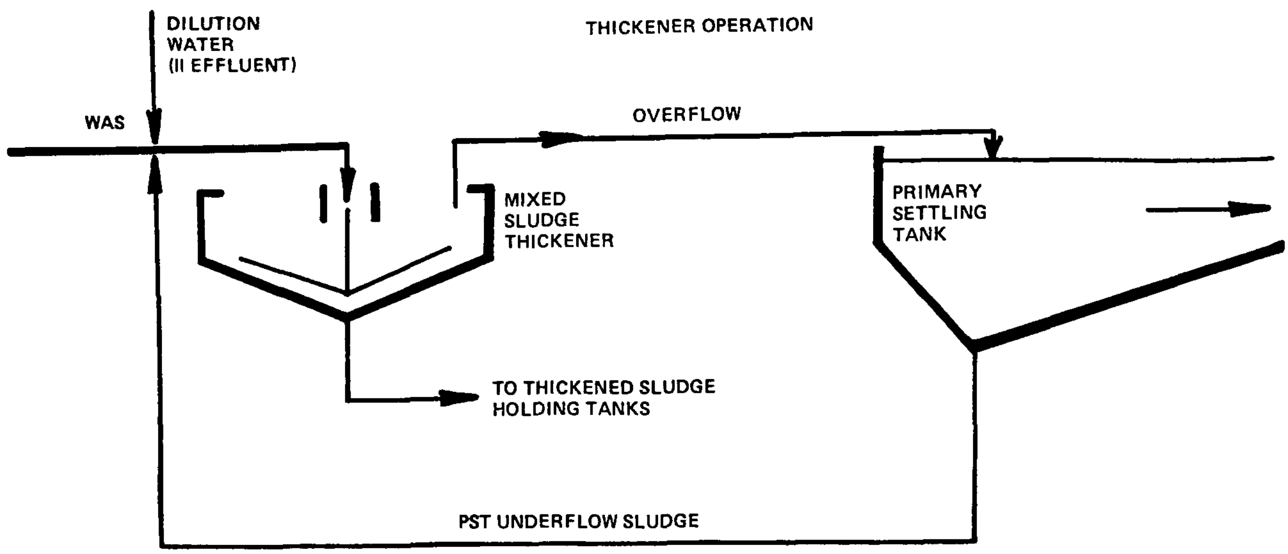

Figure 7: Thickener Operation.

magnitude of four to five percent, versus previous experience where we frequently were in the 2½ percent to 3 percent range. Partially as a result of this operating practice, we have materially improved the operations and dewatering and subsequent burning as described below.

f. Improvements in vacuum filtering and burning have encompassed recommendations which are considered good practice in other locations. We have changed the bridging in the filter valves and reduced the slurry level in the vacuum vats, maintained a differential between form and dry sections of the vacuum filter to get maximum permeability cake and maximum dryness of the cake, and have insisted that the operators run to a maximum ½ inch cake thickness. This has resulted in substantial improvements in cake dryness, which together with other changes, are partly responsible for going from 19 percent solids average in the month of December to a 23 percent solids content in March. Now, these few percentage points may not sound like much but they represent a reduction from eleven to below eight million Btu fuel burned per ton of dry solids (Figure 8). At our present costs for fuel oil, 30 cents per gallon, this represents a saving of $6.50 per dry ton and a very substantial amount of scarce fuel. Daily saving at this rate is approximately $800 at present operating levels, or almost $300,000 annually if oil becomes our only fuel.

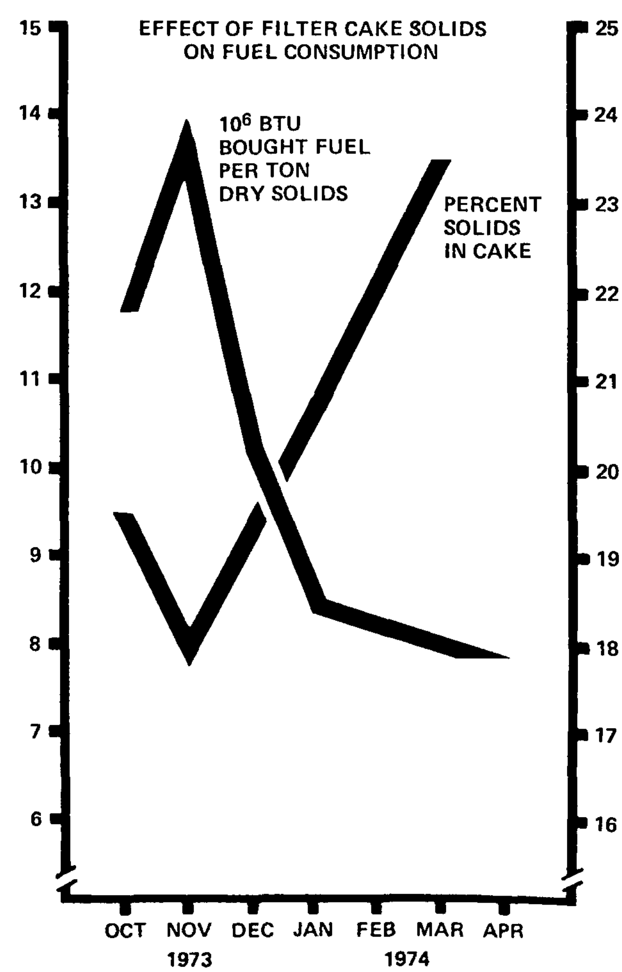

Figure 8: Effect of Filter Cake Solids on Fuel Consumption.

g. In the future, there are additional projects that will be carried out at the Metro Plant that relate to recycling efforts, First, we intend to take char from the pyrolysis project to manufacture granular activated carbon, for tertiary treatment absorber columns as in our Rosemount Plant. Second, we will be manufacturing fertilizer type products from the dried sludge, these products to be formulated for specialty purposes with predictable chemical and physical qualities. Finally, the solid waste shredding operation required for the pyrolysis system gives us the option of recovering metals. In addition, there will be manual separation of all re-pulpable kraft fiber products such as corrugated board.

Another plant in which we have programs under way for energy conservation and fuel substitution is the Seneca Wastewater Treatment Plant, which was brought into service about a year and a half ago. It has a design flow of 24 mgd and includes vacuum filtration and incinerators for sludge combustion. At this plant we have been experiencing a higher fuel requirement than we would have expected, and this has been traced partially to intermittent operation. Such operation appeared appropriate in view of the sludge quantity presently being lower than design loading. However, analysis of the operating figures shows clearly that we should run continuously at a somewhat lesser production rate and avoid the fuel that is burned during the holding period such as over weekends. For example, we found that in the whole year of 1973 and early 1974, when we were running intermittently, the total combustible material burned per pound of water evaporated was 3400 Btu per pound. In continuous operation in the month of March 1974 this figure dropped to 2900.

Because of the high fuel consumption at this plant and because of the physical arrangements that make such an experiment easy, we have set up to add coal to the sludge cake as it travels up the conveyor belt, to add calorific value to the sludge. The coal and sludge cake are mixed in the horizontal ribbon conveyor that feeds the furnaces, and further mixed by the rabbling action that occurs within the first two hearths of the furnace. This prevents premature ignition of the coal and any likely smoke that would result. The coal being used is sub-bituminous Western coal from Montana, with a thermal rating of 8400 Btu per pound and a fairly substantial moisture content, in the neighborhood of 20 percent. However, because it is brought into this area in unit trains for electric power generation, it appears to be our least costly source of fuel for this operation; estimated cost is 75 percent per million Btu.

Other operating steps that have been taken at the Seneca Plant in order to conserve on fuel without sacrificing materially on end results are these:

- We have had the operators trained to use the Ohaus moisture balance as a routine control measure for the purpose of monitoring vacuum filter performance.
- We have studied the air flotation thickening operation in order to determine if improvements could result in a lesser sludge disposal cost by production of thicker sludge.
- We have experimented with the addition of wood chips to the sludge in a manner similar to that described above for coal. The wood chips have burned effectively within the furnace and without difficulty and we will continue this work on an expanded scale.
- We have set up a program of experimentation with pulverized coal added directly to the sludge either to aid in the thickening or in conditioning of the sludge. The sludge cake would have a higher calorific value than otherwise, and thus allow combustion with a minimum of fuel oil or natural gas.

The newest of our plants, just dedicated last fall, is our Blue Lake Plant, with a design flow of 20 mgd. Here we have a minimum of energy requirement because there is no solids disposal process installed; sludge is hauled to Seneca, the plant you just saw. We have under design a system of anaerobic digestion. This will allow the utilization of the digested sludge as a soil conditioner in landspreading programs and also produce excess gas that can be used for motor vehicle fuel or blower drive.

In addition to these three major plants, the Metropolitan Sewer Board operates 21 other treatment plants in the service areas of the seven county area, and these operations are being analyzed to determine what energy savings could be accomplished by increasing concentration of sludge.

Regarding other possible energy conversion processes, there are a couple of questions that often arise in the discussions on utilizing municipal refuse as a fuel. One of these is the possible generation of electric power by raising steam. We do not consider at this time that an electric power generating plant is desirable because the thermal efficiency of conversion of heat from the refuse to electric power is only about 35 percent whereas converting the fuel into a usable source for plant operations has a thermal efficiency of 65 to 70 percent. In addition, a high flow of warmed water must be handled in some way. If usable to benefit plant operations, that may be desirable. However, it also may be environmentally damaging.

Another question that arises is the generation of utility steam and distribution to users off-site. Although this process has an indicated thermal efficiency of around 65 percent, and thus is superior to electric power production, the requirement of steam mains to the points of use raises cost of investment. Also, the load factors of the users must be reasonably stable for the process to be operated on a steady basis. That is, users who only need steam in the wintertime for building heating or in the summertime for building cooling are poor candidates. On the other hand an industrial process user who demands steam around the clock seven days a week all year long is a very good candidate. A long-term contract with users is a necessity.

In summary, The Metropolitan Sewer Board is pursuing a wide number of alternatives in the energy corservation, recovery, and substitution effort described in the foregoing. This effort will continue to occupy a significant portion of the staff of 45 engineering and scientific professionals in its various departments. This program, which began in earnest over a year before the oil crunch in late 1973, is already bearing fruit. The important factor in any choice is the reliability of a chosen method. We hope to establish this by the testing and development program now underway.

SLUDGE DISPOSAL AT A PROFIT?

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ABSTRACT

Sludge disposal is a costly operation. With the increasing concern over land or ocean disposal of heavy metal-containing sludges and the shortage of energy, alternate methods warrant evaluation. Using a wet oxidation process operating at 600 psi and 450-465°F in mildly acid conditions, 75-85 percent COD destruction is achieved. In the process, substantial quantities of surplus thermal energy are generated, the nitrogen compounds are converted to recoverable ammonia, and the metals are rendered extractable. The predominant organic compound in the resultant solution is acetic acid, which may be used as a carbon source for denitrification.

Economic studies are presented which indicate that substantial cost reductions can result from by-product recovery utilizing the PURETEC System of wet oxidation. Where denitrification is practiced, a net plant operating credit is anticipated.

In the treatment of sanitary waste, the problem of ultimate disposal of sludge has not been fully resolved. Sludge handling and disposal is a costly operation representing 25 to 50 percent of the total capital and operating cost of a wastewater treatment plant[1]. Consequently, the selection of the ultimate sludge disposal method employed can have a very significant, long-range economic impact on the community.

Additional factors must also be considered, in view of the recent trends of our economy. The current energy crisis and the long-term prognosis of general shortages in metals[2] require a re-examination of sewage sludge disposal practices to select the system with the lowest overall energy consumption combined with maximum recovery of non-renewable resources.

Sewage sludge as an energy source is significant. Based on calorimetric measurement, Brooks[3] found that sludges range from 7,500 to 10,000 BTU/pound of volatile solids. Thus, in the oxidation of sludge, substantial thermal energy generation is possible. As will be described later, it is easily possible to recover four to seven percent of the fuel value as a "clean" high molecular weight grease that can be burned directly or worked up to produce more valuable petrochemical byproducts.

Sewage sludge also serves as a marvelous concentrator of many of the metals present in the total waste stream. It is highly likely that the concentration is due to the presence of H_2S as a result of anaerobic biological activity causing the precipitation and concentration of the metals and sulfides. In the Orange County Sanitation District, it has been reported that approximately $1M/year of metals are dumped into the sewer. This is not unusual, and in Table 1, the daily metal values are

TABLE 1
Daily Metal Values Entering Plant in Pounds Per Day

Metal	*Orange County Sanitation District*[4]		*Philadelphia, Pa.*[5]		*Rockford, Ill.*[6]	
Silver	11	22	?		?	
Cadmium	50	125	8	10	4	10
Copper	400	800	300	350	400	450
Nickel	200	400	100	125	30	40
Lead	200	400	800	900	20	25
Zinc	500	1000	1200	1400	1100	1300

shown for three municipal/industrial type sewage treatment plants. The long range environmental impact of the heavy metals in sewage is of increasing concern[7]. Current landfilling and spreading of sludge is being re-examined and the desirability of continued ocean dumping is being questioned.

The preponderance of organic material in sludge, coupled with the low metal concentration, render methods such as those proposed by Dean[8], and Cadman and Dellinger[9] unsuitable for direct metal removal from sludge.

Once the organics are destroyed or reduced to low molecular weight organic acids by wet oxidation, the resultant sand or ash and solutions can be easily stripped of metals by using conventional hydrometallurgical techniques.

Sludge also represents a significant source of fertilizer, but in a different way than practiced currently. As will be described later, it is easily possible to produce either ammonium sulfate or phosphate concurrent with the sludge disposal process. Such compounds as $(NH_4)_3SO_4$ or $(NH_4)_3PO_4$ are in short supply and sufficiently concentrated to bear the freight to avoid local supersaturation of the market.

Where the denitrification process is being practiced, the purified solutions resulting from sludge disposal can be used as a carbon source instead of methanol, since the predominant species remaining is acetic acid.

Where denitrification is not required, this purified acetate-containing effluent may well be useful in some new types of flash digesters now being researched by Professor Perry McCarty at Stanford University[10]. Such use could increase the methane production capabilities and relieve the plant of ever-rising fuel costs.

Sewage sludge may well be an asset. The question is, then, how can the above possibilities be realized?

During the past three years, the Resource Recovery Systems Division of Barber-Colman Company has been investigating the application of hydrometallurgical wet oxidation practice [11-13] to the destruction of sewage sludge and many other organic waste materials. The developed system, termed the PURETEC/WETOX Process, utilizes an

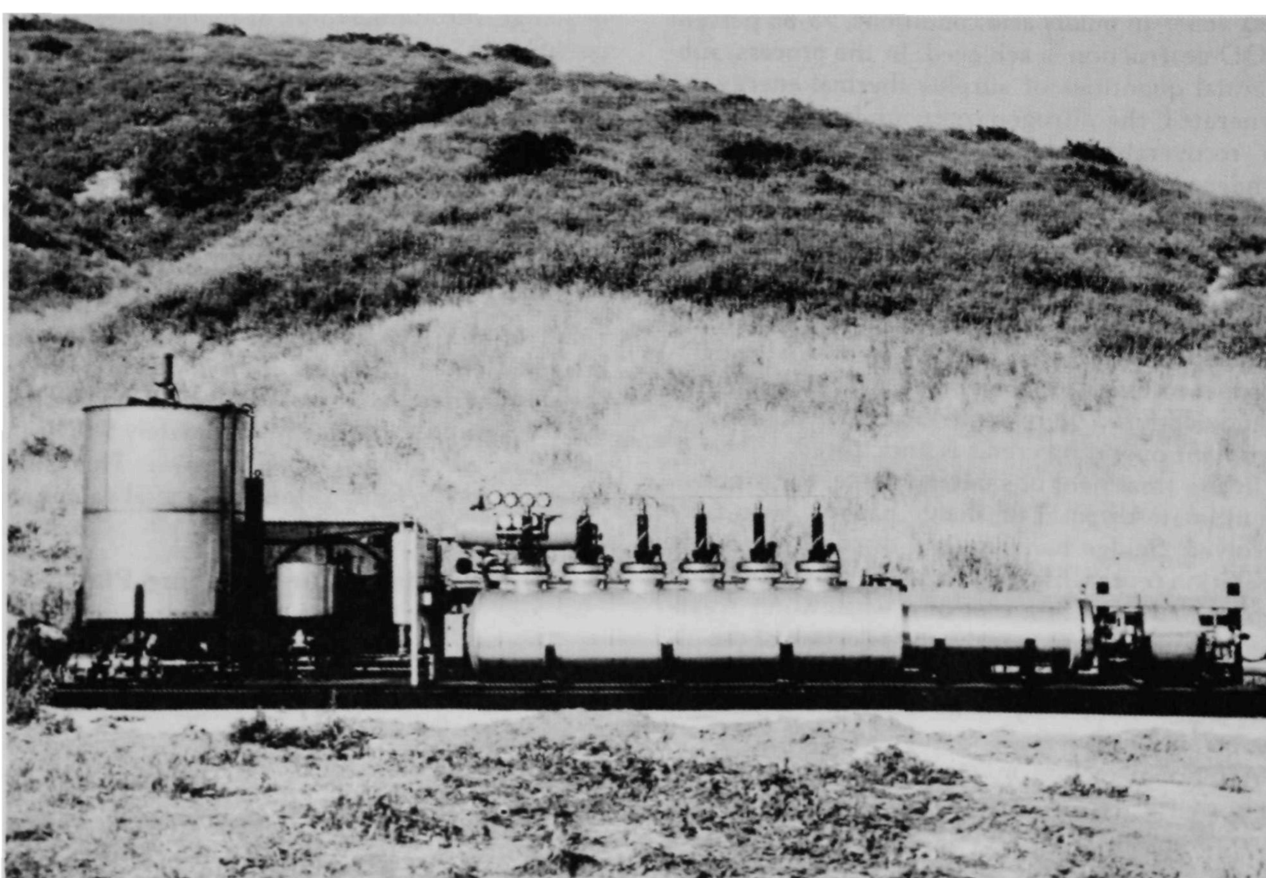

Figure 1: 4000 GPD PURETEC System.

TABLE 2
Technological Comparison of Thermal Treatment Process for Sewage Sludge[a]

	Barber-Colman PURETEC™	*High Pressure Wet Oxidation*	*Low Pressure Wet Oxidation*	*Thermal Treatment*
Process Parameters				
Temperature, °F	450	500	350	350
Pressure, psi	600	1600	350	250
Retention Time, Minutes	40[b]	80	40	60
Feed:				
pH	3	8	7	7
O_2/COD	0.7	0.7	0.1	0
Performance				
COD Reduction, %	80	80	15	10
Solids				
Weight Red., %	75[c]	75[c]	15	10
Moisture, %	50	50	50	50
Metals Removal	Removed or Insoluble	Unknown	Unknown, but difficult to remove with organic solids.	Unknown, but difficult to remove with organic solids.
Problems				
	Agitator Seals	Recycle Impact Scaling Pressure Leaks	Recycle Impact Scaling Odors	Recycle Impact Scaling Odors Non-Autogenic

[a]Comparative figures are averages obtained from operating personnel in several plants.
[b]Solids retained 60-80 minutes.
[c]Remaining solids inorganic.

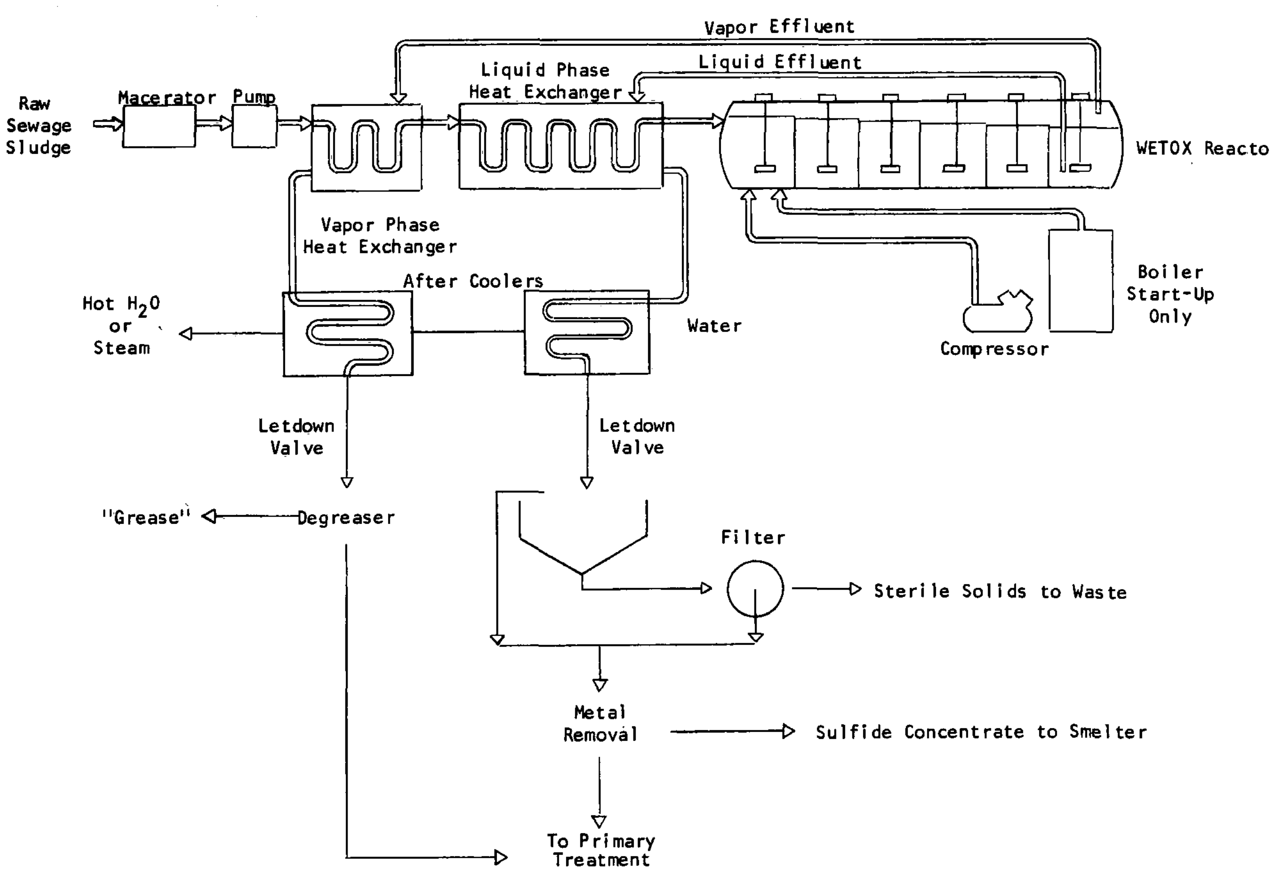

Figure 2: Barber-Colman PURETEC/WETOX System.

agitated, horizontal, multiple-compartment autoclave of the type shown in Figure 1. This reactor, operating under mildly acid conditions, consistently achieves 75 to 85 percent destruction of the COD present in any type of sewage sludge at 440 to 465°F and 600 pounds pressure. We believe that many significant improvements in the destruction of sewage sludge are possible using the above described equipment and process parameters. In addition, new routes are opened for the recovery of valuable byproducts which can substantially reduce sewage sludge destruction costs.

By way of comparison, the operating parameters and performance of various wet oxidation and thermal treatment processes for sludge are summarized in Table 2.

To more clearly define the PURETEC System, the basic unit operations we use are shown in Figure 2. As indicated in Table 2, a mildly acid media is utilized for the performance of wet oxidation. This, in part, is responsible for the increased process efficacy of the system. The acid leachant has other advantages. It avoids scaling in the heat exchanger, increases the conversion of residual organics to acetic acid and solubilizes most of the metals so that they subsequently can be precipitated as sulfides in a concentrated form. To avoid corrosion and erosion, all wetted metallic parts of the system are fabricated of titanium. This metal has an unparalleled record of immunity from attack in acid wet oxidation service. In addition, titanium is unaffected by NaCl often present in sewage sludge, especially in coastal regions.

Typical results from continuous pilot plant operation in our 4-10 System, shown in Figure 3, are presented schematically in Figures 4 and 5.

One point of significant difference which deserves further emphasis is the separation of the liquid and vapor phases prior to discharge from the WETOX Reactor. Aside from the improved performance of the heat exchanger, as much as one-third of the water present in the sludge is discharged as vapor phase condensate. This increases the residence time of the solids within the reactor, effectively increasing the capacity of the

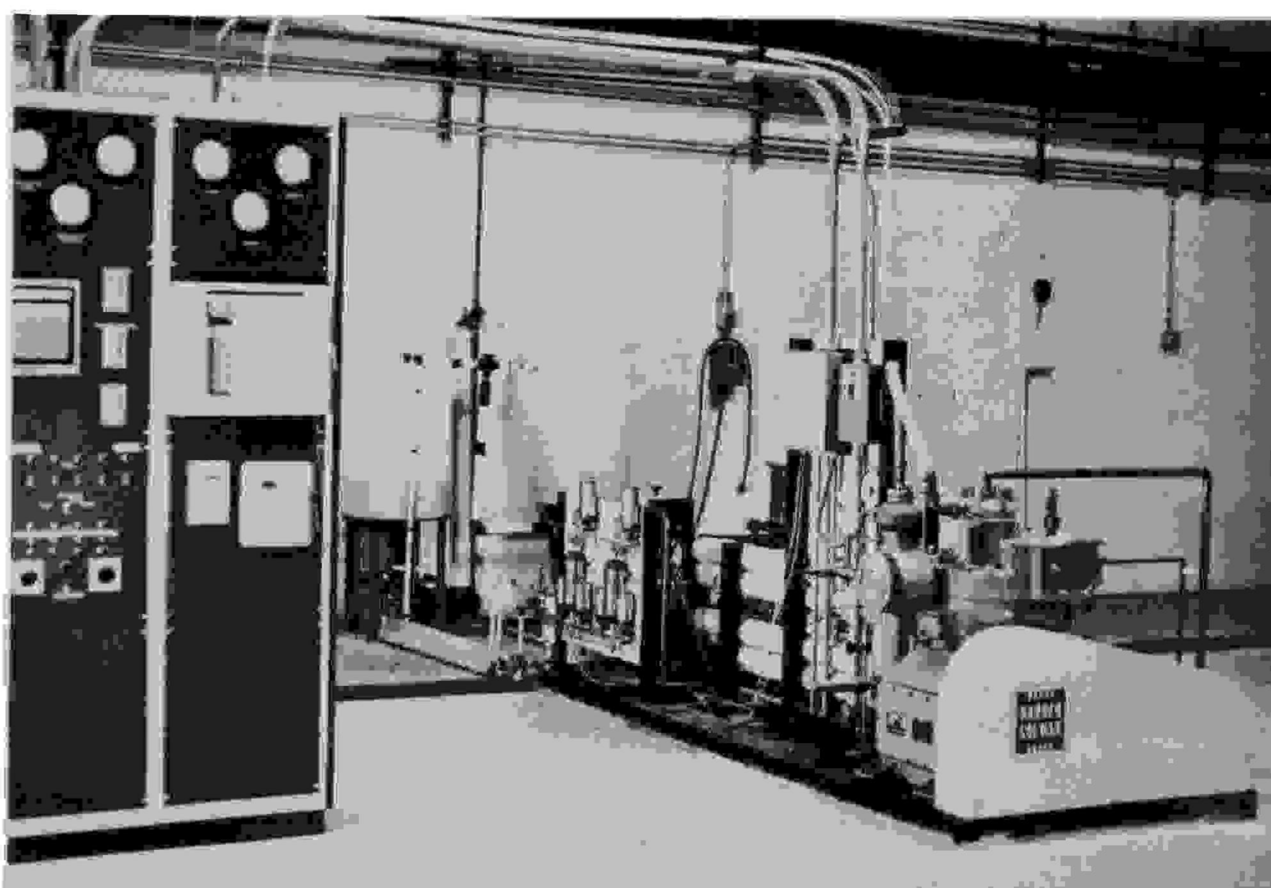

Figure 3: PURETEC/WETOX 4-10 System.

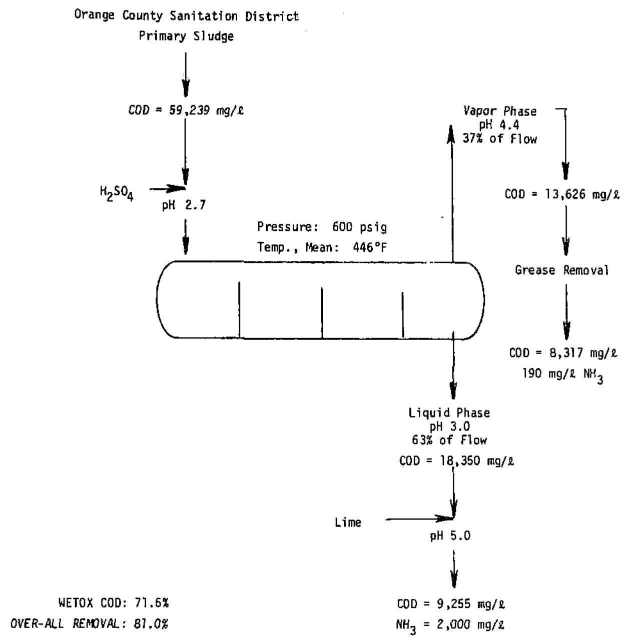

Figure 4: Continuous Pilot Plant Wet Oxidation Results, Orange County Sanitation District Primary Sludge.

system. Since no metals are present in the vapor phase, the metal concentration is increased in the liquid phase.

The vapor phase condensate also contains an easily broken emulsion of "grease" in water. While total identification of this product is not yet complete, nuclear magnetic resonance studies as well as long term saponification tests indicate that it consists of straight chain aliphatic or paraffin type organic compounds with a 190 to 250°C boiling range. Sludges normally yield 35 to 50 pounds of "grease" per dry ton of sludge treated, or approximately one barrel of "oil" per ten tons of sludge (dry) treated. This product can be burned directly or worked up for more valuable petrochemical feed stock.

The residual organic species in the vapor phase condensate, as determined by gas phase chromatography, will run 45 to 55 percent acetic acid and 15 to 20 percent propionic acid. Trace quantities of butyric acid, acetaldehyde, acetone, formic acid, methanol and ethanol are present, as shown in Figure 6.

In the liquid phase effluent, the residual organic is 40 to 70 percent acetic acid, depending on the sludge treated. Propionic acid is present in the 5 to 15 percent range, followed by lesser amounts of formic acid and acetone. Only trace quantities of acetaldehyde are present in the liquid, as shown in Figure 7.

The fate of the metals present in the sludge as a result of the wet oxidation process is of interest. The primary sludge (Orange County Sanitation District) used as an illustration of COD removal is typical. Wet oxidation, contrary to our original beliefs, does not completely solubilize all metals. It was assumed that the presence of acetate, even though only partially ionized, would leach all

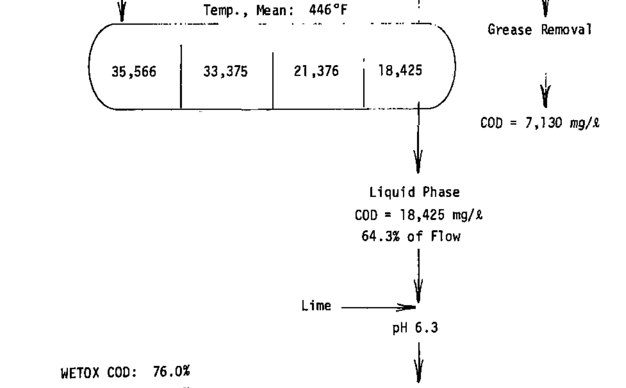

Figure 5: Continuous Pilot Plant Wet Oxidation Results, Philadelphia Northeast Digester Sludge.

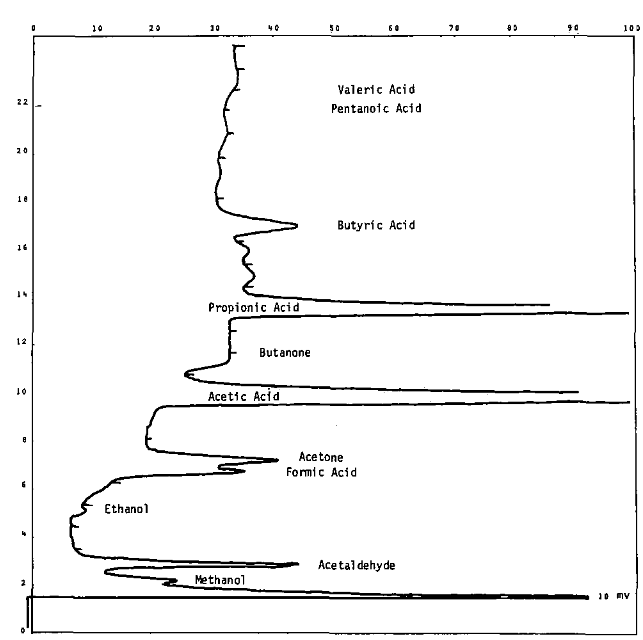

Figure 6: Gas Chromatography Analysis Vapor Phase Condensate.

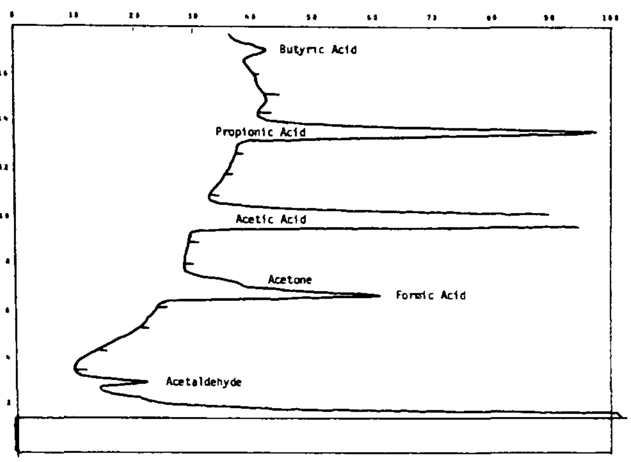

Figure 7: Gas Chromatography Analysis - Liquid Phase Effluent.

metals, since all acetates are very soluble. As shown in Table 3, as the acid concentration of the influent sludge is increased, the distribution ratio of the metals present in the liquid phase increases. With economically practical levels of sulfuric acid additions, copper, zinc and cadmium are solubilized while lead and silver remain in the insoluble residue or ash.

The soluble metals are easily removed as their sulfides, using either H_2S or preferably calcium polysulfide. The sulfide precipitate formed settles rapidly and is easily filtered. Sulfide precipitation is unexcelled in the completeness of metals removal and operational simplicity. The resultant precipitate is a high grade concentrate ready for shipment to the smelter. In the case of the Orange County Sanitation District, this "concentrate" will run about 3% Cd, 23% Cu, 11% Ni, 28% Zn and 22% S.

Based upon laboratory scale tests, the lead, silver and perhaps gold present in the ash appear

TABLE 3
Percent of Metals Present in Wet Oxidation Ash Versus Acid Addition

Metal	H_2SO_4 *Addition to Sludge Feed grams per liter*			
Wt. %	*0*	*6*	*12*	*18*
Copper	93	66	53	7
Lead	100	90	77	77
Zinc	100	66	44	0
Cadmium	97	50	38	0
Silver	98	94	87	88
Iron	98	91	92	65
Titanium	100	100	100	100
pH	5.0	3.5	1.8	1.1

amenable to chlorinated brine leaching, utilizing a process invented in 1923 for leaching lead sulfate. Lead and silver are recovered as metals ready for smelter shipment.

Acid wet oxidation of sewage sludge also results in the complete conversion of the organic nitrogen to ammonia. No oxides of nitrogen or organic amines have been detected even when oxidizing such compounds as nitrate esters or trinitrotoluene under acid conditions in the WETOX Reactor. This point is clearly evident in Figures 4 through 7.

For primary sludge, approximately 45 pounds of NH_3 are generated per dry ton of sludge treated. (See Figure 4.) This ammonia, present at a concentration of 1.32 g/L in the combined vapor phase condensate and liquid phase effluent (after metals removal) can easily be lime stripped. Because of the limited stream volume and elevated temperature of this stream (140 to 160°F), it appears theoretically practical to use an enclosed, agitated, multicompartment stripper. Based on modest mas transfer coefficients, 80 percent of the NH_3 can be stripped per stage with space time of 15 minutes per stage, resulting in approximately 99 percent removal of the ammonia. Based on a conservative recovery of 90 percent of the NH_3 at a price equivalent to anhydrous NH_3 at $180.00 per ton, this product has a minimum value of $3.65 per ton of sludge treated. Conversion to $(NH_4)_2SO_4$ or preferably $(NH_4)_3PO_4$ will enhance its value and provide a highly concentrated fertilizer to satisfy today's requirements.

The low molecular weight acids, acetic and propionic, represent potentially one of the most valuable by-products of sewage sludge wet oxidation. Acetic acid has proved to be an entirely satisfactory carbon source for denitrification[14]. Because of cost, methyl alcohol has been the preferred carbon source[15].

Based upon the combined acetate concentration of the clarified liquid phase and vapor phase effluents, 250 pounds of acetate are produced per dry ton of sludge processed. Based upon the current methanol price of $0.086 per pound, the acetic acid by-product has a value of $21.60 per ton of sludge processed.

Thermal energy is also a useful by-product of wet oxidation. Detailed studies of the energy balance of the PURETEC/WETOX System, which are beyond the scope of this paper, show that under our operating condition, five to six million BTU's of energy are available over that needed to preheat the influent sludge. This value is based on six percent solids with 70 percent volatile acids with a fuel value of 6,000 BTU's per pound of dry sludge. This energy can most economically be utilized as 180°F water or low pressure steam for heating waste water to accelerate biological activity or space heating in plant or adjacent communities. Considering fuel oil with a higher heating value of 19,000 BTU's per pound or 6.9 gallons per million BTU's and a fuel-fired boiler efficiency of 65 percent the thermal energy produced by wet oxidation is equivalent to 50 to 60 gallons of oil per ton of sludge processed. With current fuel oil costs ranging between $8.00 to $14.00 per barrel, this energy has an equivalent economic value of $10.00 to $18.00 per ton of sludge processed.

The potential recoverable by-products for a typical domestic/industrial sludge are summarized in Table 4.

In order to evaluate the economics of wet oxidation destruction of sewage sludge, relatively detailed equipment costs and operating costs have been calculated for two major wastewater treatment facilities. The first, shown in Table 5, is for the City of Philadelphia. This analysis uses the existing digester with wet oxidation for destruction of the digester sludge with metal recovery. The cost analysis is based on the current cost-effective analysis guidelines[16].

As is shown in Table 5, the total cost of sludge disposal will be $46 to $47/ton, with a plant operating credit of $36-$37/ton. These data suggest that sludge disposal costs may be reduced to approximately $10/ton.

Current sludge disposal costs are approximately $25-$30/ton, based on lagooning the digester sludge and ocean dumping. Assuming the proposed method of sludge disposal can be demonstrated on a plant basis, it appears technically and economically possible to reduce current costs.

TABLE 4
By-Product Value from Sludge Wet Oxidation Destruction

By-Product	*Value per Ton of Sludge (Dry Basis)*
"Grease"	0.80 1.40
Metals*	12.00 15.00
Ammonia	3.65
Thermal Energy	10.00 18.00
Acetate/Methanol Equivalent	20.00 - 30.00
	$46. - 68. /Ton
Ex Acetate Credit:	26. - 38. /Ton

*Metal credit based on 80 percent of Engineering Mining Journal quotes of April, 1974.

In Table 6, a similar economic evaluation is presented for the Blue Plains Wastewater Treatment Facility. Because the influent sewage is largely of domestic origin, the metal values are of no consequence. This facility, however, will include a denitrification stage and, hence, could utilize the acetic acid present in the effluent from wet oxidation.

Because of high power costs in the Washington, D.C. area, the plant operating costs are $45-$46/dry ton of sludge. Because of the possibility of acetate utilization as a carbon source in denitrification and its economic value, the by-products produced provide a credit of approximately $47/ton. Therefore, at least in theory, it may be possible to achieve a net plant operating credit from the sludge disposal plant.

It is anticipated that a large scale demonstration plant utilizing the PURETEC/WETOX System of sludge destruction will be in operation early in 1975 to verify our pilot plant results.

ACKNOWLEDGMENTS

The author would like to take this opportunity to thank Mr. Steven Townsend of the Philadelphia Water Department and Mr. Alan Cassel of the Blue Plains Wastewater Treatment Plant for providing plant operating data used in this report.

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TABLE 5
City of Philadelphia

Cost/Ton (210 Ton/Day Base)	*180 Million Gal/Day 200 Parts/Million 70% Settleable Solids*	*180 Million Gal/Day 200 Parts/Million 70% Settleable Solids*	*Credits/Ton (210 Ton/Day Base)*		*Building (15,000 Sq. Ft.)*	*Cost/20 Yrs.*	*Cost/Yr.*	*Cost (210 Ton/Day)*
$ 5.85	Thickener	Thickener			At $50/Sq. Ft.	$ 750K	$ 25K	$ .3
	105 Tons of Sludge	105 Tons of Sludge			Maintenance	300	15	.2
	5% Solid	5% Solid			Interest	525	26	.3
						$1,575K	$ 66K	$ 0.8
					PURETEC System:			
$ 7.25 (Includes Pumping)	Anaerobic	Anaerobic	Methane $ 8.00		4 PURETEC Systems	$3,900K	$ 195K	$ 2.5
	Digester	Digester	(1.40/Million BTU)		Interest (7%)	5,460	273	3.6
	90 Tons of Sludge	90 Tons of Sludge			Maintenance	3,600	180	2.0
	8% Solid	8% Solid			Labor	9,340	466	6.0
					Power	9,986	499	6.0
					H_2SO_4	1,971	99	1.0
					Lime	1,314	66	
$21.90	2 PURETEC Systems	2 PURETEC Systems	Grease	1.00		$35,571K	$1,778K	$ 21.9
			Heat	12.00	Post WETOX Treatment			
$ 4.50	Metal/Ammonia	Metal/Ammonia	Metal	12.00	Building, 5,000 Ft.²			
	Removal	Removal			at $50/Ft.²	250	12.5	.2
	45 Tons of Residue	45 Tons of Residue	NH_3	3.50	Metal/Ammonia Equip.	650	32.5	.4
	50% Solids	50% Solids			Interest	1,260	63.0	.8
					Labor	2,400	120.0	1.6
					Maintenance	650	32.5	.4
$ 7.00	Hauling	Hauling			Reagents	1,220	61.0	.8
					Power	460	23.0	.3
$46.50			CREDIT:	$36.50		6,890	344.5	4.5

Net Operating Cost: $10.00/Ton at 210 Ton/Day

TABLE 6
Blue Plains (PURETEC System)

Cost/Ton (432 Ton/Day Base)		*Credits/Ton (432 Ton/Day Base)*	
$ 6.00	Thickener		
	432 Tons/Day of Sludge		
	8% Solids		
30.08	9 PURETEC Systems	Grease:	1.00
		Thermal Energy:	21.60
	172 Tons of Residue	Ammonia:	3.65
	20% Solids	Acetate:	21.00
	Ammonia Recovery		
4.12	Acetic Acid Production		
	172 Tons Residue		
	60% Solids		
5.47	Hauling		
$ 45.67			$ 47,25

Plant Operation Credit = $1.58 per Day Ton of Input Solids

PURETEC System	*Cost/20 Yrs.*	*Cost/Yr.*	*Cost/Ton*
9 PURETEC Systems	$ 9,100	$ 455	$ 2.88
Interest at 7%	12,740	637	4.04
Maintenance	8,100	405	2.88
Labor	6,420	321	2.03
Power at 3¢/KW-HR	44,939	2,247	14.25
H2SO4	9,460	473	3.00
Lime	3,154	158	1.00
	$93,913	$4,696	$ 30.08
Post Treatment			
Ammonia Stripping/ Acetic Acid Polish	2,500	125	0.79
Interest at 7%	3,500	175	1.11
Maintenance	2,000	100	0.63
Power	2,500	125	0.79
Chemicals	2,523	126	0.80
	$13,023	$ 651	$ 4.12

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SLUDGE MANAGEMENT SYSTEM FOR ST. LOUIS

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ABSTRACT

The Metropolitan St. Louis Sewer District has two types of solids handling systems both based on the needs of the watershed for which they were designed. Anaerobic digestion with storage basins was selected for secondary treatment plant at Coldwater Creek. The plant serves an area of 41 square miles and has a design average flow of 25 mgd. Vacuum filtration, incineration and ash storage basins were selected for the two Mississippi River treatment plants—Lemay and Bissell Point. Both plants provide primary treatment for an average design flow of 424 mgd and serve an area which contains 196 square miles.

The digestion process was selected for the Coldwater Creek because an adequate area of land was available for storage of digested sludge. The methane gas from the digestion process was available for engine operation to drive blowers and pumps at an economical cost for the secondary process.

Vacuum filtration with incineration was selected for the large Mississippi River plants because of the greater volume reduction of solids and the inert characteristics of the ash material. This significantly reduced the land requirement for the two plants with large flows containing high concentration of solids.

INTRODUCTION

The Metropolitan St. Louis Sewer District was created by a vote of the people in February, 1954. The District serves an area draining 247 square miles and a population of 1,555,000 people. Approximately 3,500 industrial and commercial establishments are located within the District. Prior to creation of the District, most of the wastes generated within its boundary entered the Mississippi and Missouri Rivers without treatment.

MSD is subdivided into three subdistricts—the Mississippi subdistrict which serves 196 square miles and a population of 1,375,000; the Coldwater Creek subdistrict, which serves 41 square miles and a population of 165,000; and the Sugar Creek subdistrict, which serves ten square miles and 13,000 people. Each subdistrict has one major treatment plant with the exception of the Mississippi subdistrict which has two treatment plants. The west and south St. Louis and St. Louis County portion of the Mississippi subdistrict is served by the Lemay Plant The drainage area is 118 square miles and the population served is 785,000 persons. The northern portion of the Mississippi subdistrict is served by the Bissell Point Plant. The drainage area is 78 square miles and the population served is 592,000 persons.

Selection and Description of Treatment Plants and Processes

Coldwater Creek Treatment Plant

The Coldwater Plant is a 25 mgd average design, conventional activated sludge plant. Coldwater was the first of three major plants designed and placed in operation in September, 1965. The plant effluent enters Coldwater Creek which, for a major part of the year, is a dry stream. The effluent travels four and one-half miles in the Creek before entering the

Missouri River ten miles above the City of St. Louis Water Intake. Since the effluent enters a dry stream which discharges above the City water intake, secondary treatment followed by chlorination was chosen as the basis for design.

Sludge treatment employs gravity grit removal, primary sedimentation, sludge thickening, anaerobic sludge digestion with digested sludge lagoon storage on the plant site.

Anaerobic digestion was the only method of sludge handling considered due to the plant size and location. At that time the area around the plant site was undeveloped and primarily of rough wooded topography. Therefore, adequate and suitable land was available for disposal of digested sludge by storage in sludge lagoons, or basins. Since considerable farmland and pastureland existed, some thought was also given to land spreading of liquid digested sludge as a supplement to storage. A 38 acre tract was acquired and developed into four cells of approximately five acres each. At the present rate of filling the sludge basins should provide adequate storage for 25 years. Should future development result in land for additional sludge storage being unavailable, the option of pumping the digested sludge to the Bissell Point Plant for incineration and disposal could be considered.

Lemay and Bissell Point Treatment Plants

The Lemay Plant is a primary treatment plant designed to treat 173 mgd prior to discharging its effluent to the Mississippi River. This plant was placed in operation in May of 1968.

The Bissell Point Plant is the larger of the Mississippi River subdistrict treatment plants with a design average flow capacity of 250 mgd. The Bissell Point Plant was officially placed in operation in November of 1970. This primary effluent is also discharged to the Mississippi River. Because of these direct discharges to the Mississippi River, which provide an approximate dilution of one part of wastewater to 1000 parts of river water, and due to Federal requirements at that time, primary treatment was the major consideration at these two plants.

The liquid wastewater treatment processes at both the Lemay Plant and the Bissell Point Plant are similar. Flow is pumped into gravity grit removal tanks, followed by comminution of solids, preaeration of the wastewater, and primary sedimentation for removal of settleable solids and floating material.

Sludge treatment consists of vacuum filtration of primary solids followed by incineration. Incinerator ash is slurry pumped and stored in ash drying basins located at each plant. The following eight solids-handling processes were considered for sludge treatment prior to design of the two plants:

1. Digestion, vacuum filtration and incineration
2. Digestion, vacuum filtration and trucking cake to fill
3. Digestion, vacuum filtration and production of soil conditioner
4. Digestion, pumping of liquid sludge to lagoons
5. Digestion, barging of sludge to lagoons
6. Fresh sludge vacuum filtration and incineration
7. The Laboon Process
8. The Zimmermann Process

Of the above eight alternatives, digestion with pumping to lagoons and digestion with barging to lagoons had the lowest total equivalent annual cost for both plants. These two methods, however, were considered unsuitable for the Metropolitan St. Louis Sewer District plants because of the following:

The combined flow of the Lemay and Bissell Point Plants was estimated to be 424 mgd for the design year 1985. The average daily solids removal was estimated at 273 tons per day or 1,086,000 gallons of sludge per day at six percent solids. After digestion a total of 183 dry tons of solids had to be disposed of to the lagoons. This would result in a flow of 726,000 gallons of digested sludge at six percent solids.

The land area required to store the above quantity of sludge is very large. Computations showed that by 1985 nearly 450 acres of land would be filled and abandoned, and by year 2000, over 750 acres would be used. To protect the future operations of the District, it was concluded that the initial design should involve purchase or option to purchase at least 1,000 acres of land suitable for lagooning.

Suitable tracts of land of this size, of low enough value to be considered for this purpose, can be found in the vicinity of St. Louis only as flood plain areas along the Mississippi River. A survey was made of sites which might be available for sludge lagoons. The closest site was 18 miles from Bissell Point with a net usable area of 290 acres. The next site was an island in the Mississippi River located 23 miles from Bissell Point with a net usable area of 390 acres. The last possible site was located 40 miles away with a net usable area of 755 acres.

The operation of digested sludge lagoons on such a scale along the Mississippi River would be subject to a number of serious difficulties. The most important of these, perhaps, is the possibility of contamination of water supplies. The low-lying islands available for sludge lagooning are composed of river bottom sand and silt, underlain by extensive gravel and sand formations. These gravel formations form an aquifer from which many nearby wells draw water for both public and private supplies. The Missouri cities of Crystal City, Festus and Herculaneum are all located near the proposed lagoon sites, and all have public water supplies using wells. The possibility existed that seepage from the sludge lagoons could enter the porous formations and find its way into these water supplies. Because of the large areas involved, there appeared to be no method available that would be practical and economically feasible to seal the lagoons and prevent seepage.

A second problem concerning the public health would result from the necessity to discharge the supernatant liquor to the Mississippi River. This liquor would be relatively small in quantity, but high in BOD and alkalinity. It was not feasible to pump the supernatant back to the sewage treatment plants for treatment. Although the effect of such a discharge on the river is debatable, it was possible that the public agencies having jurisdiction would have voiced an objection. A third factor involving the public health was the possibility that flood waters could breach the lagoon dikes, and release large quantities of sludge to the river. In this connection it should be mentioned that the economic evaluation was based upon lagoon dikes constructed to river stage 35. Under this plan, it was recognized that the dikes would be overflowed at about five to seven year intervals with the consequent inundation of the lagoon areas. Following such a flood, the excess flood water would be drained off, and the dikes repaired. It was found impracticable, from the standpoint of cost, to provide dikes high enough to protect against the maximum flood, since the additional cost of the higher dikes would have exceeded $1,000,000.

The lagooning of sludge on a scale as large as required in this case, involved several other problems as well. It would have been difficult, if not impossible, to prevent the entry of unauthorized persons into the large lagoon areas, in spite of fences, and the hazards of drowning in the 10 to 14-foot depth of the lagoons would surely have been present. The prevention of insect and vermin breeding would have been another problem encountered, and although the potential odor and insect problems could have been adequately controlled in a small sludge lagoon, it would have been difficult to provide complete control in a lagoon installation on the order of 1,000 acres in size.

Another feature which adversely affected the selection of lagooning was the loss of extensive land areas from agricultural, wildlife and recreational uses. Removing such large areas permanently from more productive uses, and devoting them simply to storage of sludge could have provoked considerable adverse reaction from the public.

Because of these considerations, anaerobic digestion followed by lagoons was not selected even though it had the lowest equivalent yearly operating cost.

The next lowest alternative was vacuum filtration of primary sludge and incineration of solids. This process has two distinct advantages for plants that have large flows and large quantities of solids. These advantages are volume reduction and solids sterilization.

During vacuum filtration, the solids content is increased from 6 to 30 percent solids. During incineration all moisture is evaporated from the solids and the volatile portion is burned off at 1600°F. The volatile content for the two Mississippi River plants was estimated to be 63 percent. Based on this value a total of 101 tons of ash had to be disposed of daily. Thus the total land requirement for ash basins for a 20 year design period was 13 acres with fill to depth of 12 feet. Land sites for disposal of ash of this quantity were available within a short distance from each plant.

Incinerator ash is non-putrescible, sterile, inert material. It may be disposed of without concern of objectionable odor problems or public health nuisances. Because of volume reduction and solids sterilization, the District chose vacuum filtration and incineration as the method of treating wastewater solids at the two Mississippi River plants.

Operational Problems and Solutions

Coldwater Creek Plant

The Coldwater Creek Treatment Plant, utilizing digestion for solids handling, was put on the line in September,1965. There are six digesters, 100 feet in diameter with a center depth 25 feet. Each digester has a volume of approximately one million gallons. Four of the tanks have fixed covers while two are equipped with floating gas holders with a gas storage of 125,000 cubic feet each.

Digester temperatures are maintained by recirculating sludge through heat exchangers employing hot water recovered heat from the pump and blower engine operations. Digester mixing is accomplished by two methods, bottom gas mixing and conventional heat exchanger pump recirculation applied to the first stage digesters only.

The digesters were started in a normal manner by filling them with raw sewage and raising the contents to an operating temperature of 95°F. Lime was used to maintain the pH at an operating range of 6.8 to 7.0 and by early March, 1966, the system was operating effectively. Upsets have occurred over the years, primarily due to heavy metals.

Early in 1967, anhydrous ammonia was very effectively utilized to adjust the pH during one such upset. In the spring of 1967, the scum line became plugged. Attempts to open the line by mechanical means were unsuccessful due to the many horizontal and vertical bends in the line. Sections on the line were relaid to reduce the number and degree of the bends. Subsequent plugging has been avoided by employing a steam-cleaning process routinely on an annual basis.

In the fall of 1969, assisted by grant money from the Environmental Protection Agency, a study was conducted to identify odors associated with the operation of a sludge thickener. As part of the study, the thickener was covered with a styrofoam dome in order to control the atmosphere immediately over this unit. The dome continues to serve as an excellent means of controlling odors around such a unit.

A unique method of digested sludge elutriation is practiced utilizing chlorinated plant effluent to provide a buffering solution in digested sludge disposal operations. This process has been an excellent aid in controlling odors from the sludge lagoons.

In general, the plant is in the ninth year of continous operations and has not experienced any serious sludge handling problems. No additional sludge handling provisions are contemplated or planned for the near future.

Lemay Plant

The Lemay Plant has been in operation for six years. During the last fiscal year 1972-73 the average flow was 117 mgd. The wastewater received is relatively weak with influent suspended solids averaging 161 mg/1 and the effluent 69 mg/1. This is equivalent to a suspended solids removal of 57 percent for the year. A total of 17,314 dry tons of solids were vacuum filtered and incinerated during the year and the volatile content of the sludge averaged 50 percent.

Six vacuum filters with stainless steel coil spring media are used to dewater solids removed from the primary tanks. During the first two years of operation, extremely poor vacuum filter results were achieved. The vacuum filter yield averaged only three pounds per square foot per hour coupled with an extremely high moisture content of approximately 80 percent. During this period the raw wastewater contained highly flocculated solids which produced excellent suspended solids removal in the primary clarifiers. However, the sludge did not compact in the clarifiers and sludge depths of two to four feet were constantly maintained. The chemical demand for sludge vacuum conditioning prior to vacuum filtration was extremely high, producing a chemical cost of approximately $15.00 per ton during the first six months of operation.

From the appearance of the solids, it was evident that a large quantity of industrial waste material was causing poor settling of the sludge and high chemical costs for vacuum filtration. Through a vigilant sampling program by material was determined.

A manufacturer of paint pigments was disposing of large quantities of bentonite clay as a process waste. The bentonite clay, a flocculent aid, absorbed large quantities of water which could not be chemically removed and thus, could not be properly dewatered on the vacuum filters. Motivated by discussions held and particularly by the implementation of the District's Industrial Waste and Surcharge Ordinances, this company installed equipment to drastically reduce the quantity of bentonite clay discharged.

With the reduction of this material, a significant improvement in the operation of the vacuum filters was noted. Moisture contents decreased from 80 to approximately 70 percent. Since the bentonite clay material is a non-volatile material, the volatile content of the vacuum filter cake increased from 39 to 50 percent. Vacuum filter yields nearly doubled and chemical conditioning costs decreased from ten dollars to about five dollars per ton.

The plant began operation using ferric chloride and lime as conditioning chemicals for vacuum filtration. After six months of operation with poor filtering results, cationic polymers were tried. A significant reduction in cost was immediately noted. A short time thereafter, anionic polymers in combination with the cationic polymers were investigated and a further reduction in cost was realized. Over the years, chemical conditioning costs have steadily decreased from $5.00/ton in 1969 to $1.70/ton in our last fiscal year of 1972-73.

Lemay has three 11-hearth, twenty-to and one-half foot diameter incinerators. The vacuum filter cake is belt-conveyed into the top of these incinerators. Complete combustion of the organic portion of the solids takes place along with the complete evaporation of moisture and seven-fold reduction in solids volume.

As with the vacuum filters, a more efficient incineration operation has been achieved over the past six years. During the first two years of operation, some problems were encountered due to the high moisture content of the filter cake discharged to the incinerators. The moisture, along with the low volatile content, caused excessive gas consumption for heat of evaporation resulting in high operating costs. The additional heat requirements created severe operating problems. The rabble arms on both inhearths 4 and 6 had to be replaced more frequently than normal due to the excessive amount of heat rising through the center drop hole of the incinerator on these hearths.

With the lower moisture content and the higher volatile solids content achieved by the elimination of the bentonite clay, the quantity of gas required to maintain the incinerators at operating temperatures between 1400 and 1600°F decreased. Gas consumption was reduced from 125 therms per dry ton to 40 therms per dry ton. The volatile content of the solids now contributes 90 percent of the total heat requirements for the incinerators operation. The additional ten percent heat is obtained by burning natural gas. In 1972-73 this amounted to $2.34/ton incinerated. With the reduction of gas usage, the problem of warping arms in hearths 4 and 6 was significantly reduced. Clinker formation in the incinerator was also reduced considerably.

Incinerator ash is screw-conveyed into a slurry tank where primary effluent is added. This ash slurry is then pumped three-fourths of a mile to three ash-basins. The ash settles out readily upon entering the basins and the supernatant is decanted to the Mississippi River. The ash basins at Lemay occupy a total land area of 13 acres. At present loading rates the basins will provide ash storage for approximately 20 years.

Bissell Point

The Bissell Point Plant provides primary treatment for a current dry weather flow of 120 mgd which is 60 percent domestic wastewater and 40 percent industrial wastes. Less than 15 percent of the flow is from a sanitary system while the remainder is from an old, combined sewer system within the City of St. Louis.

The wastes treated are strong with COD that fluctuate from 600 to 2900 mg/1, BOD which average 300 mg/1 and suspended solids which average 335 mg/1. The suspended solids removal in the primary basins averages 55 percent resulting in 92 dry tons of solids to be treated daily. In addition, approximately eight wet tons of grit are removed each day.

The vacuum filters are of the cloth-belt type with a surface area of 500 square feet designed for a maximum vacuum of 24 inches of mercury (12 psi). A total of ten filters can serve the five incinerators. A common conveyor belt receives the sludge cake from a pair of filters and delivers it either to an inclined belt for direct feed to the top of the incinerator or to a transfer belt for feed to another incinerator.

Excellect filtration results were obtained during the spring of 1971, before all the sewage was being intercepted using lime (about five percent) and ferric chloride (less than one percent). Sludge cake moisture contents were on the order of 65 percent with yields holding at about 5.5 pounds per square foot of filter surface. Cost per dry ton of conditioned sludge averaged about $1.50 during this period.

A problem with the lime unloading system occurred early in May, however, and the conditioning system had to be altered to handle a single liquid cationic polymer that was at that time being used at the Lemay Plant. This was supplemented in late July with a dry anionic polymer. Generally, yields dropped significantly, averaging below 2.0 pounds in September and consequently costs rose and held at above ten dollars per dry ton. The lime-ferric system was back on line by mid-November and costs dropped to about three dollars per ton and yields as high as ten pounds per square foot were achieved.

Since then, lime and ferric chloride have been the basic sludge conditioning chemicals used at the plant although there have been several plant-wide runs with polymers of different manufacture. These experiences have indicated that the polymers used could only be successful in the winter months when there is no chance of septicity, and that consistency of results with polymer conditioning was virtually impossible to achieve over even a modest period of time.

Current experience at Bissell Point with lime and ferric chloride for sludge conditioning indicates yields of about nine pounds of dry solids per square foot per hour with a lime addition of 11 percent and ferric chloride at about 3.5 percent, at a cost of $5.85 per dry ton of sludge filtered.

Bissell Point is less fortunate than Lemay, in that two ash basins with a total capacity of only 160,000 cubic yards are available for temporary ash storage. Approximately 50 tons of ash per day are slurried to the basins for storage. One basin is presently full and will require removal of the ash to another fill site. Approximately twice as much ash as at Lemay, about 18,000 dry tons per year, must receive ultimate disposal.

CONCLUSIONS

The Metropolitan St. Louis Sewer District chose two types of solids handling systems for its two major subdistricts. Anaerobic digestion with storage lagoons was selected for the secondary plant at Coldwater Creek which serves an area of 41 square miles and has a design average flow of 25 mgd.

The digestion process was selected for the smaller plant because adequate land area was available for storage of digested sludge. The methane gas from the digestion process was available for engine operation to drive blowers and pumps at an economical cost for the secondary process.

Vacuum filtration, incineration and ash storage basins were selected for the two Mississippi River subdistrict plants—Lemay and Bissell Point. Both plants provide primary treatment for an average design flow of 424 mgd and serve a watershed of 196 square miles. Vacuum filtration with incineration was selected for the large Mississippi River subdistrict plants because of the greater volume reduction of solids and the inert characteristics of the ash material. This significantly reduced the land requirement for these two plants with large flows and high concentrations of solids.

Both of the above solids systems were selected based on the needs of the individual watersheds. Both systems have provided an excellent degree of solids treatment at their specific location.

THE ENVIRONMENTAL PROTECTION AGENCY'S RESEARCH PROGRAM

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I am pleased to participate in this National Conference on Municipal Sludge Management because of the importance of providing environmentally sound alternatives for the handling, disposal, and utilization of sludges generated at municipal sewage treatment works.

Sludge processing and utilization are clearly a most important factor in the design, operation and costs of wastewater treatment. For example, approximately 35 percent of the capital costs and 55 percent of the annual operation and maintenance costs are associated with sludge production.

The Water Pollution Control Act Amendments of 1972 set deadlines for the implementation of secondary and best practicable treatment for municipal wastewater which will require upgrading of a large portion of the wastewater treatment works in the country. This upgrading of treatment levels will result in increased volumes of municipal sludges. The Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532) additionally limits the practice of ocean disposal of sludges. These laws will impact the sludge disposal problems and practices of most metropolitan areas of the country.

The Environmental Protection Agency's municipal waste inventory indicates that approximately 34 percent of the sewered population is served by less than secondary treatment. An additional five percent (7.3 million) is served by treatment systems which, in large measure, do not meet the performance requirements of secondary treatment. Thus, treatment facilities for 39 percent of the total U.S. population will require upgrading to meet new requirements. Upgrading will have a substantial impact on the total quantity of sludge generated nationwide.

New and improved technology must be developed and demonstrated to meet the current and future needs of municipalities. The task of achieving an orderly improvement of sludge disposal practices must be a cooperative effort by local jurisdictions, state agencies, private industry and the Federal Government. The nine billion dollars to be made available for the construction grants program through FY 1975 will assist an estimated 6,000 projects, many of which will be wastewater treatment facilities generating large volumes of sludge. The research arm of EPA is deeply involved in the development and demonstration of new and improved technology to support the continuing construction grants program.

Research and development associated with municipal sludges is a key element in our program. About 20 percent of our resources are specifically allocated to sludge problem solving. It should be noted also that nearly all other technical areas within the Municipal R&D program are involved in some way with sludge. Development of new treatment processes nearly always results in the production of more sludge or changes the sludge characteristics. Sometimes both happen. Sludge aspects, therefore, are considered in everything we do. One of the reasons we were interested in the development of pure oxygen activated sludge systems was that such systems offered the potential to produce less sludge with improved dewatering characteristics. Phosphorus removal processes produce more sludge which is difficult to dewater. Control of combined sewer overflows will result in greatly increased quantities of sludge to dispose of. It has been estimated, for example, that control of combined sewer overflows in Washington, D.C. will double the amount of sludge to be handled. In short, all portions of the collection, transport and treatment system are inter-related and all have an influence on the volume and characteristics of the resulting sludges.

One of our major objectives is to demonstrate developed technology at full-scale in order to evaluate cost and performance, the information required by treatment works planners and designers before new technology can be placed into field practice.

Examples of such demonstrations include the Cedar Rapids pressure filter project and the Denver aerobic digestion project discussed in detail earlier in the Conference. Two other recent projects worthy of note include a "top-feed" vacuum filter developed under an EPA contract and a capillary suction dewatering device. The "top-feed" filter will be demonstrated at Milwaukee. Estimates of cost and performance indicate that sludge dewatering savings, with full conversion to the new filters, would amount to about one million dollars per year in capital and operating costs. Filter yields and cake solids are expected to be significantly greater than bottom feed filters.

The unique capillary suction device was developed for dewatering activated sludge with minimum use of conditioning chemicals, coupled with reasonable capital and operation and maintenance costs. St. Charles, Illinois will conduct the full-scale demonstration.

New initiatives in the beginning stages include:

a. Investigation of the applicability of pyrolysis as a sludge disposal technique. This work is being conducted by the Bureau of Mines through an interagency agreement with EPA. The Bureau will apply its past research expertise on pyrolysis of coal, utilizing pilot scale units, to thermally degrade differing sludges and sludge-solid waste mixtures. Pyrolysis may offer advantages of minimal air pollution and by-product recovery in the form of oil or gas. The project will yeild information on processing conditions nature and amounts of by-products, air pollution characteristics and identification of any new water pollution problems which may develop through use of the process.
b. An interagency agreement with the Department of Agriculture will result in an evaluation of land application and filling procedures for dewatered sewage sludge. Work will include identification of the effects of nitrogen form and movement, pathogen persistence and movement, metals presence and plant uptake.
c. Information on thickening and dewatering rates of sludges generated by phosphate removal processes will be obtained under a contract with Envirotech-Eimco Division. Better selection of process hardware will be possible once this information is available, hopefully resulting in lower processing costs.
d. Seattle METRO will demonstrate and evaluate the application of sludge in a forest environment. It is expected that the project will identify the effects of sludge application on forest growth, establish effective methods of application, establish application rates which can maximize forest growth and minimize impact on ground and surface waters and establish short-term effects on the forest organisms, physical and chemical characteristics of forest soil and the chemistry of soil water.

Technology areas identified for early starts include demonstration of anerobic or aerobic thermophillic digestion; evaluation of wet oxidation; disinfection of sludge by pasteurization, sonics and radiation and further work on sludge incineration or co-incineration with solid wastes.

Efforts toward investigation of the fate and effects of heavy metals, pathogens and nitrates for land application systems should be greatly expanded as soon as possible. The health effects aspects of sludge utilization and disposal must be resolved in order to adequately identify the "effectiveness" portion of the cost/effectiveness picture so important to planning, design and public relations.

Conference discussions have concentrated almost exclusively on unit processes. Sludge thickening and dewatering, anaerobic and aerobic digestion, heat treatment, land application and several other subjects have been covered. This seems to be the approach at most conferences. I don't want to discount the validity of this approach, since it is the stuff that most research is made of and a large number of plant operating problems seem to focus on unit processes. I suggest that we should include the techniques of system planning and design in our technical meetings.

When we design and construct treatment works we are not designing and building unit processes, we are designing and building *systems.* Once the works are in place, the manager must operate a treatment *system.* Mr. Garrett alluded to this in his paper earlier in the program, as did Mr. Cassel a bit later.

Recent changes in water pollution control requirements, national economics and our national resource picture, particularly energy, make it extremely important that more thought be given to control and treatment *systems* as opposed to unit processes. It should be routine to carefully examine all aspects of the treatment system so as to obtain lowest system capital cost, efficient and dependable performance, minimum O&M costs, minimum energy requirements and full utilization of energy sources available within the system. Hundreds of alternatives and trade-offs are possible in establishing the system of choice. Time does not permit detailed discussion of this subject, but I would like to encourage discussion of techniques that have been or could be used for this purpose during future conferences. Complicated study matrices are required for the large metropolitan areas and I know that the Metropolitan Sewer Board of the Twin Cities used this approach in selecting their future system.

In closing, I hope that the modest Federal research and development efforts will be supplemented and complemented by the private, municipal and State sectors. Active participation by all sectors will be necessary to solve our sludge problems. The EPA involvement is to a large extent for the purpose of assistance in assuming the risks associated with research, development and demonstration. The private and municipal sectors must be involved to ensure that technology advancements will offer truly cost/effective alternatives.

Movement of improved technology into practical field application will not be accomplished with reasonable speed unless the technology can be demonstrated in full-scale installations. Such demonstration is necessary to determine operating efficiencies, characteristics, costs and design data.

I would like to encourage each of you to help achieve these objectives. Without your full support and interest it will be extremely difficult to advance technology toward more cost/effective solutions to our many pollution problems. I encourage you to develop new ideas and concepts to deal with the sludge problem and keep us informed of your ideas and needs.

SUMMARY OF "PRETREATMENT AND ULTIMATE DISPOSAL OF WASTEWATER SOLIDS CONFERENCE" - HELD MAY 21-22, RUTGERS UNIVERSITY

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There was a total of 15 papers, the first nine dealing with characteristics of sludge, its stabilization, incineration, thickening, dewatering, chemistry, and economics. The next six dealt with various aspects of ocean disposal.

Dr. J.B. Farrell, EPA, presented an "Overview of Sludge Handling and Disposal", (contents of paper not summarized here).

Mr. B.V. Salotto, EPA, summarized analytical results on sludges, principally of the digested type, taken from 33 wastewater treatment plants in the United States. They had been analyzed for 20 metals, nitrogen, phosphorus, and sulfur. The BTU value of some sludges was also determined. Atomic absorption method was used for the determination of metals. No detectable amount of beryllium was found in any sample analyzed.

Mathematical analysis of the data indicated that the distribution of heavy metals in sludge is approximately log/normal. This behavior is characteristic of all sludge types analyzed thus far. Comparison of the levels of metals in the United States sludges with corresponding levels in Scandanavian sludges show higher levels in the United States sludges. Variation of any one metal in sludges of a particular wastewater treatment plant was much less than in sludge samples taken from different plants.

Major emphasis of continuing work will be to more accurately define the composition of sludges produced by secondary treatment plants processing municipal wastewaters.

Mr. C.A. Counts, Battelle Northwest, discussed his work on the stabilization of municipal sludge by high lime dosage. There were two objectives: (1) determination of the degree of stability produced by large lime doses, and (2) the effect of spreading lime sludges on crop lands.

The conclusions were: (1) the lime dosage required to raise the pH to 11 or 12 varied as the sludge character, that is, the higher the solids content the higher the lime dosage required, (2) the pHs decayed over time (24 hours being the chosen time) unless an excess of lime was employed, (3) a pH of 12 resulted in 99 percent inactivation of the bacterial population, although fecal strep was fairly resistant, (4) to prevent regrowth of the bacterial population it was necessary to maintain a high pH, (5) the odor of the sludges was pronouncedly decreased by lime treatment, (6) lime treatment improved the settling characteristics, and (7) improved the soil productivities measured in both green house and outdoor test plots.

The treatment is cheap (about ten dollars per dry ton) and is recommended for small treatment plants, as an auxiliary when the plant exceeds capacity, or in the case of emergency.

The next paper by *Stephan Hathaway of EPA* dealt with thickening characteristics of treated sludge.

Phosphate removal from municipal wastewater can be accomplished by adding Al or Fe salts to the primary clarifier. Sludges produced differ from conventional primary sludges in thickening and other dewatering characteristics. The thickening characteristics of these sludges have been investigated using bench-scale gravity thickening equipment and a pilot-scale air flotation thickener.

Both the Al-primary and the Fe-primary sludges show poorer thickening than do conventional primary sludges. Gravity thickening of both types of sludges was ordinarily poor. However, if the sludges were diluted with effluent, thickening rates and solids content of settled sludge increased substantially.

Factorial experiment demonstrated that an increase in the level of either Al or Fe in the sludge produced poorer air flotation results—solids content of floated sludge was lower and losses to underflow were higher. Polymer addition reduced losses to the underflow and increased solids content of the floated sludge.

Mr. Darryl Cook, Eimco Division of Envirotech talked about dewatering of sludges.

Physical chemical sludges produced by coagulation precipitation in a 100 gpm pilot plant were thickened and then dewatered. Parallel laboratory studies were performed with the pilot plant on identical sludge samples in an effort to improve the efficiency of the dewatering and obtain a correlation where possible.

Lime, alum, and ferric chloride sludges were produced, polymer being used with the alum and ferric chloride studies.

Lime sewage sludges were found to dewater very well with no chemical addition. Alum sewage sludge dewatered well when lime was added as a conditioning chemical. Ferric chloride sewage sludge contained large amounts of ferrous sulfide which hindered dewatering. There were some indications that ferric chloride sewage sludge containing ferrous sulfide could be dewatered using a conditioning pretreatment of ferric chloride followed by lime.

In a discussion of "Thermal Degradation of Sludge", *R.A. Olexsey, EPA* pointed out that incineration is an increasingly important sludge disposal technique and currently accounts for about 25 percent of the sludge disposed of in the United States. Before a sludge can be incinerated it must be dewatered to a solids content approaching 30 percent. This dewatering is expensive since mechanical dewatering costs average twelve dollars per dry ton of sludge.

The multiple hearth is the most common type of incinerator used for sludge combustion although the fluidized bed is becoming increasingly popular. Other types of incinerators used are the flash dryer, the rotary kiln, and the cyclone furnace.

Sludge incinerators consume considerable amounts of auxiliary fuel and can contribute to air pollution if not properly controlled.

Some of the feasible alternatives to sludge combustion are pyrolysis, combined incineration with solid waste, and wet oxidation. These methods are largely in experimental and demonstration stages.

R.L. Kaercher in a paper on incineration design presented a general discussion of incineration problems and, together with a discussion of the Federal and State emission regulations, a plea for more reasonable standards was made.

Some of the problems with each were considered while the multiple hearth followed by wet gas scrubbing was presented as the most practical.

D. Derr of Rutgers University outlined the economics of sludge disposal systems. He suggested procedures for the estimation and evaluation of costs for alternative sewage sludge disposal systems.

On considering the various disposal methods, (1) incineration, (2) landfill, (3) ocean disposal, and (4) land disposal other than landfill, he analyzed each method into its component parts and generalized these into the following basic processes: transport, dewatering, and storage.

Solids concentration was confined to two levels, 5 percent and 30 percent.

In the various options the dewater-no-dewater option is incorporated.

Flow charts were presented for the various disposal methods combining alternate routes. Employing standard financial procedures the authors calculate in cost per dry ton the various steps in the disposal system so that by suitable combination the total cost of the proposed system can be estimated.

Dr. J.V. Hunter, Rutgers University talked about "Future Problems in Sludge Production Handling Systems". The basic chemical reactions in alum, ferric chloride and lime treatment to remove phosphate were discussed. While coagulants used together with alum or ferric chloride produced a greater weight of sludge, increased size of digestion facilities will probably not be required. However, the presence of the aluminum, iron or calcium salts may interfere with the digestion process. Anaerobic digestion of sludge containing aluminum phosphate or iron phosphate does not result in appreciable dissolution of the phosphate. The solids content of treated sludges increases in the order of alum, iron chloride, and lime. A similar situation prevails for the dewatered sludge.

Some work has been done on regeneration of the inorganics, the lime offering the most promise of success. However, a viable process is still a long way from operational, if indeed it ever will be.

The next six papers were devoted to ocean disposal of sludge.

Dr. W.F. Rittal, Pacific Northwest Environmental Research Laboratory, EPA, Corvallis, Oregon, presented a paper on the Koh-Chang model for the barged release of sewage sludge to coastal waters.

While this model has not been verified under field conditions, it *has* been evaluated by several other agencies. The model has three computer programs, for barges with puff, jet and wake-plume convection. The capabilities of the model were demonstrated by showing the results of the calculation for disposal of sludge in the New York Bight under both summer and winter conditions. The charts and curves have been computed for depth versus waste-cloud drift, dilution versus time, depth versus concentration, and other parameters. There is no other procedure or model available to the regulatory programs which provides this degree of analysis. It will therefore be of significant value to those with the responsibility of safeguarding the marine environment.

Presently, a study to modify the model for estuarine use is being funded.

Dr. Mullenhoff, Oregon State University, described interesting research on laboratory studies of sludge degradation. Aerated sea water was passed over an inch deep sludge bed contained in a glass vessel. In experiments whose duration was up to 80 days the water and sludge were exposed to both normal and elevated pressures. Oxygen uptake *by* and carbon content decrease *in* the sludge were determined. Methods of analysis including a sludge respirometer for oxygen uptake are described. Curves of the total carbon content were drawn as a function of time. Both the surface and the bottom of the bed showed initial rapid decreases for the first 40 days and then a plateauing for the next 40. The reaction was treated as first order and a rate constant derived. Equipment has been constructed to carry out similar studies on deeper sludge beds.

He also described some underwater sludge studies conducted for a week in the Bahamas at a depth of 150 feet.

Mr. Richard Dewling, Director, Surveillance and Analysis Division, EPA, Edison, New Jersey described the dumping problems in the New York Bight and the Philadelphia areas where large quantities of dredge spoils, sludge, waste acid and toxic materials are dumped annually. The problem of sludge will be exacerbated when, with the completion of secondary treatment plants in New York City, sludge requiring disposal will be tripled.

Although the sludge depth is only five feet deep in the Bight, the depth of the dredge spoils is about 40 feet. NOAA is presently selecting two alternate sites for sludge dumping to be used if an emergency develops. Despite reports of a "sludge monster" creeping along the bottom towards the New York beaches, Mr. Dewling believes the dumping is safe so far as recreational waters are concerned for three to five years. At that time a solution will have to be available. Perhaps controlled ocean dumping in different areas for limited times to allow recovery of the benthic life will be the answer. Both incineration and landfilling, as far as New York is concerned, have definite drawbacks.

Dr. Portmann, Ministry of Agriculture in England reported the British view on ocean disposal of sludge. They have been dumping from Manchester, Glasgow and London increasing quantities of sludge for the past 50 years until the total is now some 8,000,000 tons annually. Extensive tests have shown little damage to benthic fauna or commercial fisheries. This explains why the authorities continue to be favorably disposed toward sewage sludge disposal at sea. For the past five years dumping has been regulated by a "voluntary scheme" although a new dumping law is pending in Parliament. The British sludge problem is probably abated by the large tides, reaching 20 feet in the Thames, and the consequent swift currents which disperse the sludge very rapidly. Dr. Portmann presented data on the sludge heavy metal content. He also described the use of a radioisotope of silver in following the sludge drift after dumping. Increases in ocean dumping are largely traceable to the growing sentiment against land disposal which is generated by increased distance transport costs and by the fact that most sewage sludge results from a mixture of domestic and industrial wastes.

Mr. F.K. Mitchell, University of California at Berkeley. In Santa Monica Bay about 1.3 million gallons of sludge diluted with 3 million gallons of secondary effluents to facilitate pumping are discharged daily from an outfall seven miles into the bay at the edge of the Santa Monica Canyon at 320 feet. From a second outfall five miles long 335 mgd of combined primary and secondary effluent are discharged. Both outfalls have been in operation since 1960. Depth profiles of sedimental heavy metals concentrations indicate that the depths of significant quantities of sludge particulates are greater than one foot near the outfall and one foot or less at distances greater than two miles down canyon from the discharge. Chlorinated hydrocarbons in the surface sediments present a picture similar to that of the metals. Total DDT and PCB concentrations are higher in the canyon in the shallow areas of the bay and are highest by far at locations closest to the sludge outfalls. Biological monitoring in the vicinity of the discharge shows that the area is by no means a biological desert.

Dr. D. Dorman, Monmouth College, reported on bioassay methods. A multidisciplinary approach appears to be the most satisfactory one. Determination of the disposal site far enough in advance of its use to allow adequate base-line data surveys, including chemical, physical, and biological parameters, should be made. Subsequent field and bioassay monitoring, on a programmed basis, would then be utilized after waste disposal began. In addition, no single test organism can provide the necessary data to determine the impact evaluation of a disposal site. Extrapolation of the responses of one species, or of several species, might not include the response of the most sensitive species if that organism was not included among the test species. A multidisciplinary approach with constant monitoring would possibly provide enough data to assess the impact on single species and, more importantly, in the food web. Additional safeguards, as promulgated by bioassays and impact evaluation, could then be made at the effluent and waste disposal sources to reduce possible toxicants to levels manageable by marine organisms.