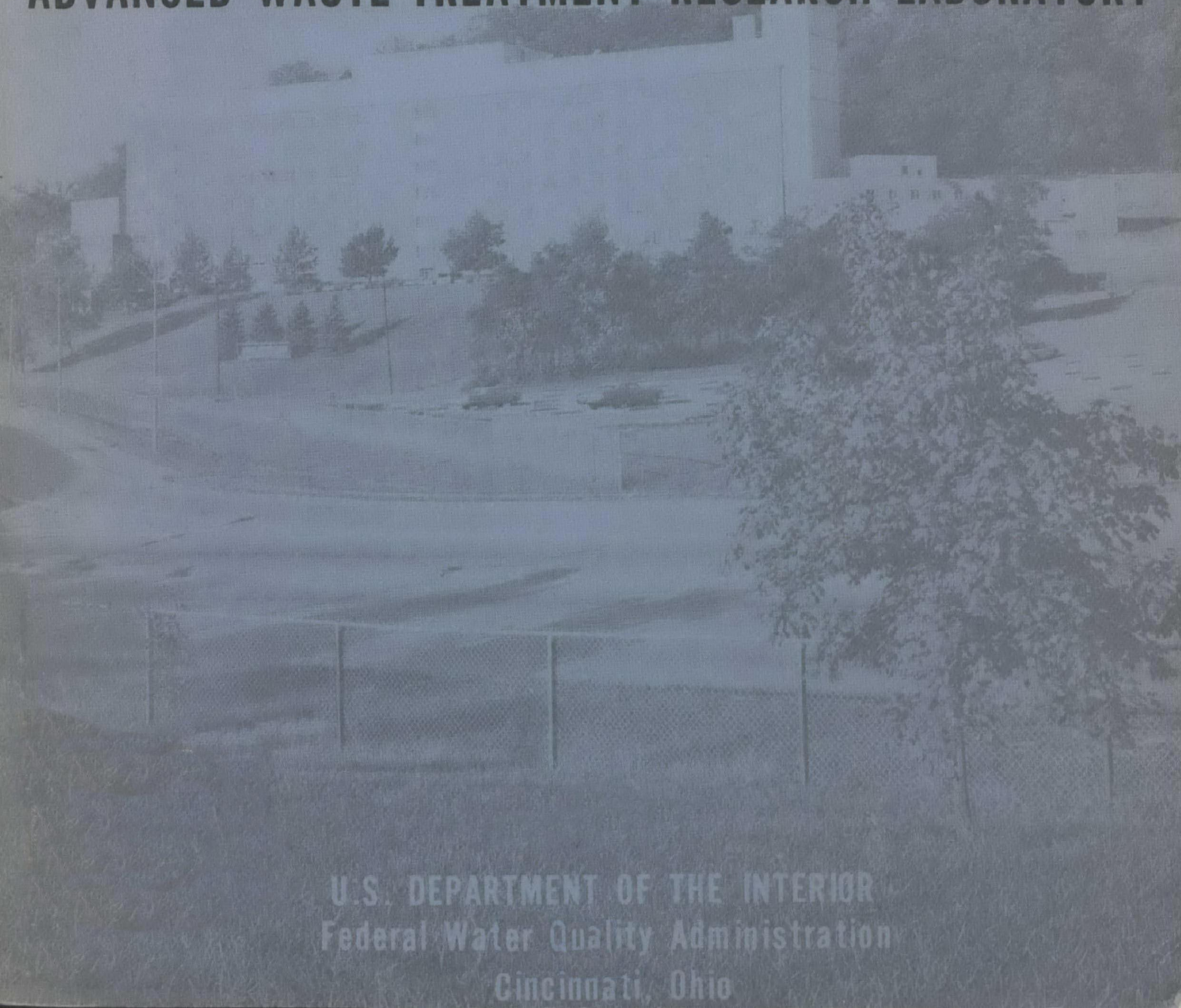
CURRENT STATUS OF ADVANCED WASTE-TREATMENT PROCESSES

JULY 1, 1970

ADVANCED WASTE-TREATMENT RESEARCH LABORATORY



U.S. DEPARTMENT OF THE INTERIOR
Federal Water Quality Administration
Cincinnati, Ohio

CURRENT STATUS OF ADVANCED
WASTE TREATMENT PROCESSES

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FOREWORD

Waste treatment technology is moving rapidly nowadays. A huge impetus has been given to this field by the substantial sums of money made available for research by the Congress and administered by the Research and Development Office of the Federal Water Quality Administration. The Advanced Waste Treatment Research Laboratory (AWTRL) in Cincinnati, Ohio is a key element in conducting treatment research for FWQA.

This status report is current as of July 1, 1970. It reports the programs of the Advanced Waste Treatment Research Laboratory but mentions other pertinent work as well. It is not, however, a comprehensive review of the field. The purpose of the report is to inform Federal Water Quality Administration operating and managing officials of the state of the art of treatment. It is expected others will find it useful. If the details of the scientific investigations are desired, they are available in various reports named in the text.

F. M. Middleton
Director of Research
Advanced Waste Treatment
Research Laboratory

ADVANCED WASTE TREATMENT RESEARCH LABORATORY

Cincinnati, Ohio

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

PPB 1101 & 1105	Municipal Pollution Control
PPB 1700	Waste Treatment and Ultimate Disposal Technology
PPB 1603	(Biological Identification of Pollutants) Virus Studies

DIVISION OF PROCESS RESEARCH & DEVELOPMENT
FEDERAL WATER QUALITY ADMINISTRATION
U. S. DEPARTMENT OF THE INTERIOR

MUNICIPAL POLLUTION CONTROL TECHNOLOGY
PPB - 1101 - SEWERED WASTES

APPLICATION OF ADVANCED WASTE TREATMENT PROCESSES TO THE TREATMENT OF MUNICIPAL WASTEWATER

Transfer of advanced waste treatment technology from laboratory scale or experimental pilot plant scale is taking place through the continuing evaluation and development of specific processes and treatment systems in large-scale pilot plants and full-scale demonstration plants. The following discussion covers specialized treatment processes that have achieved full-scale application. Comments are made as to the general effectiveness and limitations or disadvantages of such processes under actual use conditions.

PURE OXYGEN IN ACTIVATED SLUDGE PROCESS

Promising results were obtained from a study recently completed at Batavia, New York in which the use of pure oxygen was compared with air in the activated sludge process. The test plant has two identical and separate 1.25 mgd trains. Each treatment train has separate aeration tanks, final sedimentation tanks, and return sludge facilities. Primary sedimentation is not provided. One train was covered and converted to use of pure oxygen and operated in parallel with the air system. With recent developments in oxygen production and dissolution technology, under the conditions of the Batavia test, pure oxygen was shown to be competitive with air. The oxygen can be produced economically on site.

Under test conditions the pure oxygen train achieved 90 percent or more BOD removal at detention times of 1 to 1.5 hours. With 3 hours detention time BOD removal averaged 85 percent for the air train and 93 percent for the oxygen train. Another significant difference in performance was quantity of waste activated sludge. Although confirming data are needed, preliminary results indicate a reduction of 30-40 percent. Further information will be obtained during a continuation of the study.

Based on the Batavia data, cost estimates projected for new plants indicate the possibility of lower capital investment and operating costs for the pure oxygen treatment. The major factor contributing to the cost reduction is the ability to carry higher MLSS and thereby reduce aeration tank capacity to 40 or 50 percent of that required for the conventional systems. Additional savings are indicated for sludge handling and disposal.

Results of the study are being published as an FWQA research report titled "An Investigation of the Use of High Purity Oxygen Aeration in the Conventional Activated Sludge Process." Copies of the report, expected to be ready by September 15, 1970, may be obtained by writing Planning and Resources Office, Office of Research and Development, FWQA, Department of Interior, Washington, D. C. 20242.

Further evaluation and development of the pure oxygen process will be accomplished under terms of an FWQA R&D Grant recently awarded to New York City. A 20 mgd train at the Newtown Creek treatment plant will be converted to the use of pure oxygen and operated for at least 12 months.

The use of pure oxygen for the treatment of municipal waste waters is being aggressively promoted by Linde Division of Union Carbide Corporation who was contractor for FWQA on the Batavia study.

GRANULAR ACTIVATED CARBON

The use of granular activated carbon for removal of nonbiodegradable organics, color and residual BOD has been demonstrated in full-scale plants and is felt to be sufficiently developed to be used on full-scale applications wherever conditions warrant such treatment. Because suspended solids are partially removed on the carbon, the solids load and need for pretreatment must be considered when designing a carbon adsorption system. In order for the carbon treatment system to be economical, the used carbon must be regenerated and reused. Large-scale plants currently using and regenerating granular activated carbon include the 7.5 mgd plant at Lake Tahoe and the 0.5 mgd plant at Nassau County, New York. A number of articles have been published covering the Tahoe plant. One appeared in the June, 1969 issue of Civil Engineering entitled "Wastewater Reclamation and Export at South Tahoe." A few copies are available from the Cincinnati Laboratory.

At the 300,000 gpd Pomona, California Pilot Plant secondary effluent is applied directly to the carbon columns without requiring excessive backwashing. This is only possible, however, because of exceptionally high quality secondary effluent at this location. Results of this study will appear in a 1970 issue of the Chemical Engineering Progress Symposium Series.

Full-scale evaluation of granular carbon adsorption as a replacement for biological treatment will be obtained on a 10 mgd plant at Rocky River, Ohio. This is an R&D Grant project which involves chemical pretreatment of raw sewage in an improved primary treatment ahead of the carbon columns. Construction of this plant is scheduled for completion by fall of 1971. Further details regarding design and operating conditions scheduled for this plant may be obtained from Mr. A. N. Masse, Cincinnati, Ohio.

PHOSPHORUS REMOVAL

Phosphorus removal from wastewater on plant scale has been carried out for a number of years at certain locations where the water was needed for industrial reuse purposes. It has been relatively recent, however, that phosphorus removal has been considered necessary as a pollution control measure.

Although purely biological methods of phosphorus removal have been proposed, it appears that addition of chemicals to the water to precipitate the phosphorus is the only dependable method. Chemicals that can be used are iron salts, aluminum salts, and lime. The simplest method for carrying out chemical precipitation is to add the chemicals at some point in a conventional activated sludge plant. The point of addition can range from before primary treatment to near the exit of the aerators. Iron salts and aluminum salts are preferable to lime. A number of R&D Grant projects have been sponsored by FWQA including Grand Rapids, Michigan at 45 mgd. Contact Mr. E. F. Barth, Cincinnati, Ohio for additional information.

An alternative method for carrying out precipitation of phosphorus is by using a clarifier-settler combination either for treating screened raw sewage or as a tertiary treatment. Lime presently appears most appropriate for this method of removal. Excellent phosphorus removal can be obtained along with a high degree of solids removal, especially if the settler is followed by a filter. Probably the best known example of tertiary chemical clarification is the 7.5 mgd plant at Lake Tahoe. Reference has been made to this plant in connection with carbon treatment. Other FWQA supported projects include plants at Colorado Springs and Nassau County. When chemical clarification is used for treatment of raw sewage, it can serve as the first stage of a purely physical-chemical treatment system. Under an R&D Grant, a 5 mgd plant will be constructed and operated at Painesville, Ohio that utilizes chemical clarification followed by carbon treatment. There is increasing interest in this type of treatment system. Additional plants are likely to be constructed in the near future.

AMMONIA STRIPPING

Up to 95 percent of the ammonia in wastewater can be air-stripped from solution using about 400 ft^3 of air per gallon of water treated. Effective ammonia removal requires a pH of 11. A nitrified secondary effluent cannot be treated by this method.

A $3\frac{1}{2}$ mgd ammonia stripping tower has been operated at South Lake Tahoe to treat one-half of the total flow at that location. This is part of a two-stage lime precipitation process. Lime is added in the first stage to raise the pH to 11. This step removes most of the suspended solids, phosphates, and carbonate compounds. Effluent from the first-stage clarifier is then subjected to countercurrent air contacting to remove ammonia; effluent from the stripping tower is recarbonated with CO_2 to precipitate excess calcium as $CaCO_3$ in the second-stage clarifier; at this point the pH is dropped to 9.5.

Although the process has been quite effective in reducing the ammonia content of the wastewater, operational problems raise questions as to the desirability of promoting the widespread use of ammonia stripping towers. The process is subject to freezing problems in cold climates and reduction of the ammonia removal efficiency at low temperatures. Lime deposits on the slats and superstructure of the tower create serious maintenance problems. At this time, use of stripping towers will most likely be restricted to more temperate locations where freezing is not a problem or areas where high percentage removal is not required during winter months.

POLYMER ADDITION TO PRIMARY SEDIMENTATION

The addition of polymers to raw sewage to improve sedimentation of suspended solids was studied at the District of Columbia Water Pollution Control Plant. The study was carried out at full scale on this 240 mgd plant. The test involved three separate phases in which each of three polymer suppliers carried out extended studies with his own most effective polymer. Best results were obtained with anionic polymers used in doses of less than 1 mg/l. The amount of solids removed by sedimentation increased by as much as 25 percent. Because of hydraulic overload at the plant, which affected operation of the final settlers, the improved primary treatment did not improve overall treatment significantly. For plants having only primary treatment, however, use of polymers could increase effectiveness of treatment significantly. Use of polymers to improve primary treatment may also improve secondary treatment where organic load to the aerators is very high. Additional results of the study will be reported in an FWQA research report entitled "Raw Wastewater Flocculation with Polymers at the District of Columbia Water Pollution Control Plant." Copies are expected to be available from FWQA's Research Division by October 1, 1970.

COMBINATION CONVENTIONAL-AWT TREATMENT

The treatment plant at South Tahoe, California is probably the best known advanced treatment plant in the country. Reference has already been made to the plant several times. It is of 7.5 mgd capacity and includes conventional primary treatment and activated sludge treatment followed by tertiary processes including two-stage lime clarification with ammonia stripping between stages, pressure multimedia filtration and granular carbon treatment. The effluent from the plant is of high clarity and contains only traces of phosphorus and organic materials. The water is presently exported to Nevada for eventual use in irrigation of crops after prior holding in a recreational lake, Indian Creek Reservoir. The lake can be used for all types of water recreation including contact sports. Use has been restricted, however, by a lack of facilities. Because of the high quality of the water, algae are not a significant problem.

Since biological treatment is included in the Tahoe system, the system is a hybrid between conventional and purely physical-chemical advanced treatment. There is increasing interest in pure physical-chemical systems. These have the advantage of not being affected by toxic materials that can upset the operation of biological processes for long periods. They also require less land area. Where only organic and phosphorus removal is required, chemical clarification followed by carbon treatment are the processes considered most reliable at this time. R&D Grants at Rocky River and Painesville, Ohio utilize variations of these processes. The effluents from these plants will not be of as high a quality as that from the Tahoe plant. The effluents are expected to be the equivalent of secondary effluent. Where nitrogen removal is required, ammonia stripping or selective ion exchange are most likely candidates. Stripping is less expensive but is subject to several operating problems. More work is needed to develop a completely satisfactory physical-chemical nitrogen removal system.

DESIGN MANUALS FOR ADVANCED WASTE TREATMENT PROCESSES

We have recognized the need for improved methods of disseminating results from research and development programs and we are currently making arrangements for a series of treatment process design manuals. These manuals will supplement technical seminars and publications covering results of the Advanced Waste Treatment Laboratory inhouse and extramural projects.

The information needed by consulting engineers for design of advanced waste treatment plants is now available for some processes.

However, the data are contained in numerous segmented publications, reports and manufacturers' literature. The purpose of the manuals will be to compile available information in a form which can be readily utilized, and provide detailed information on hardware selection and system design.

Contracts are being negotiated for preparation of the following design manuals:

1. Activated carbon adsorption, primarily for the treatment of secondary effluent or an equivalent waste stream.

2. Phosphorus removal by chemical treatment and solids separation.

3. Suspended solids removal including such techniques as micro-screening, filtration, tube settlers, etc.

4. Upgrading of existing plants through the application of such techniques as pure oxygen treatment, flow equalization, etc.

Target date for completing the first manuals is March, 1971. At that time the manuals should be ready for general distribution to consulting engineers and other treatment plant design interests.

Flow Reduction From Individual Homes and
Alternative Waste Collection Systems

FLOW REDUCTION

A study on state-of-the-art of methods for flow reduction has been completed by Electric Boat Division of General Dynamics Corporation. This study concluded that use of modified plumbing fixtures for flow reduction is economically feasible and would result in cost savings in many cases. There are many household functions in which water is used wastefully. Water usage could be reduced up to 35 percent by use of presently available devices and technology. Feasible devices are shallow trap toilets, toilets with separate flush cycles for urine and feces, flow control showers, and faucet aerators. Treatment and reuse of wastewater in individual homes is not economically feasible, except for filtration and reuse of wash waters or aerobic unit effluent for toilet flushing in water-short areas.

A study is planned for demonstration of flow reduction devices and technology for 8 homes. Present water usage will be monitored prior to installation of modified plumbing fixtures. The program will include:

4 homes with flow control showers and shallow trap-dual cycle toilets

2 homes with flow control showers and with recycled (filtered) wash water reused in normal trap-dual cycle toilets

2 homes with shallow trap-dual cycle toilets and flow control showers, and with recycled (filtered) wash water used for lawn watering

PRESSURE SEWER SYSTEMS

Collection and treatment of wastewater at a central point should be utilized where feasible in lieu of individual home systems. However, it is not always practical to install conventional gravity sewer systems because of rough terrain and necessity for rock excavation. One possible solution is use of a pressure system, which is being studied under an R&D Grant at Grandview Lake, Indiana.

The Grandview Lake system will serve about 60 homes initially. Individual grinders and pumps will be installed at some homes. Septic tank effluent will be pumped directly without grinding at others. Three and one-fourth inch PVC pipe will be used for the pressure sewer with 1-inch connections from homes. Wastes will be treated by a combined anaerobic and aerobic lagoon. Lagoon effluent will be utilized for irrigation of a hay field.

The individual home pump and grinder unit was designed using commercially available home garbage grinders, pumps, and check valves. Unit cost without installation is $450 to $500.

VACUUM SEWER SYSTEMS

One of the most interesting developments in water closets and waste collection is the Liljendahl vacuum system. This system uses air rather than water as the major transport system for a vacuum toilet. A vacuum toilet requires only one-half gallon per flush compared to 4 to 6 gallons for conventional toilets. The vacuum system can also be utilized for waste collection from groups of homes in lieu of conventional gravity sewers.

The Sanivac Division of National Homes Corporation is marketing the Liljendahl vacuum system. This system has been used in Europe, the Bahamas, and in Latin America. A grant project is being developed for demonstration of the vacuum system in an area now served by septic tanks. Connections with house sewers will be made at lot lines. Another grant is planned for demonstration of the vacuum toilet system.

ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

MUNICIPAL POLLUTION CONTROL TECHNOLOGY
NON - SEWERED WASTES
PPB 1105

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

INTRODUCTION

A study on state-of-the-art of individual home waste treatment systems has been completed by Electric Boat Division of General Dynamics Corporation (Report 11050 FKE, "Flow Reduction and Treatment of Waste Water from Households," available September, 1970). In addition, an inhouse survey of proprietary equipment developed by industry but not now commercially available has been conducted.

SEPTIC TANK SYSTEMS

At the present time, there are approximately 15 to 17 million septic tanks in use. 1.4 million new systems have been installed since 1960. In many cases, operation of septic tank systems has not been satisfactory and has resulted in health hazards. This is due to poor soils which do not readily accept effluent. Lack of maintenance by homeowners is also a contributing problem. Regulatory agencies now require large lots in areas with low soil permeability. This has prohibited housing developments in many areas. However, in areas with high soil permeability and low population density, septic tanks usually perform satisfactorily and will continue to be an acceptable disposal method.

Septic tank costs are upwards from $120 and installation from $250. Tile field costs vary from $200 to $2400 depending on type of soil and regulatory requirements.

ACTIVATED SLUDGE PACKAGE PLANTS

Individual home aerobic package plants have been marketed since about 1955. It is estimated that there are 20,000 to 30,000 units now in operation. Initially, State health departments allowed discharge to natural waterways. Because of periodic discharge of suspended solids, subsurface disposal is now required by most regulatory agencies. Unit costs vary from about $800 to $1600 installed. If filtration and disinfection are required, costs are increased by $300 to $800.

DEVELOPMENT OF IMPROVED SYSTEMS

If an acceptable individual home treatment unit to replace septic tanks could be developed, a multimillion dollar market would exist. This potential market has induced industries to expend funds for R&D. From results of the inhouse survey, there are 5 companies that have conducted studies on unit development. In several cases, system components and total systems are now ready for field evaluation.

The basic problem in unit development is acceptable capital and operating costs. The Electric Boat study has concluded that use of advanced treatment processes, including distillation, reverse osmosis, electrodialysis, chemical treatment, and activated carbon adsorption, is not economically feasible at this time.

The basic problem area is solids disposal, as is the case for large-scale conventional treatment. Capital and maintenance costs for incineration are expected to be high. Another problem area is air pollution potential of incineration. Solids could be stored in the unit and disposed of similarly to sediment from septic tanks. However, this may not be aesthetically acceptable to all homeowners.

Fail-safe design is necessary. Homeowners tend to ignore operating and maintenance requirements for presently available package plants. There have been cases where power to units has been shut off. Policing of a large number of units by regulatory agencies is difficult. A possible solution to maintenance requirements is a permanent service contract with the manufacturer.

FUTURE STUDIES

In view of effort expended by industry on development of new equipment and approaches to individual home treatment, support of basic research on new systems or hardware development is not planned at this time. Planned studies include demonstration of commercially available hardware and modifications to improve treatment, and new proprietary equipment developed by industry. Studies on the relative absorption rates of effluent from package plants as compared to septic tanks will be conducted.

ADVANCED WASTE TREATMENT RESEARCH LABORATORY

CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

VIROLOGY

PPB 1603 - 1706

Division of Process Research & Development

Federal Water Quality Administration

U. S. Department of the Interior

Virology Section
Robert A. Taft Water Research Center
Cincinnati, Ohio
1603-1706

Introduction

Large quantities of viruses of human origin are present in sewage, sewage effluents, and in rivers and streams. Viruses of animal, plant and bacterial origin must also abound in these waters, but their presence is not as well documented, and their importance to the human animal is largely unknown.

The viruses of human origin are small in numbers compared with the numbers of bacteria that are excreted. Moreover, viruses do not multiply outside of living susceptible cells, and these numbers decrease even in that most nutritional environment constituted by domestic waste. The great importance of viruses in water, however, lies not just in their numbers, but in their great capacity to infect their hosts. The smallest amount of virus capable of infecting the most highly susceptible cells in cultures, our most sensitive indicators of infection, is usually capable of producing infection in man.

The clear capability of minimal quantities of viruses for producing infection in man is sufficient justification for seeking the total removal of viruses from any waters which man might consume. The permissible level for viruses in such waters should be none.

Epidemiology

Small amounts of viruses ejected into rivers and streams with partially treated wastewater become a potential hazard to downstream recreationalists and to those in downstream communities who must consume these waters. Even 19 PFU per 50 gallons of river water, an amount we have recovered with an inefficient technic even in cold months, constitutes a considerable hazard, for what this means in terms of the amounts of viruses that may enter the intakes of any community every day is readily calculable.

Unfortunately, small amounts of waterborne viruses may infect swimmers and consumers and not be readily detected by the effect they produce. This is so because small amounts of ingested viruses are likely to produce infection, but not disease. Infection is the state whereby the virus enters and multiplies within susceptible cells. It is a disease state with no overt signs. Overt disease exists when sufficient damage has been done to bring about systemic malfunctions. Thus, individuals infected with small amounts of virus may show no signs; yet, they may excrete large amounts of virus, their contacts may be infected with large amounts and recognizable illness may result. The spread of infection and disease in this fashion will appear to be by the personal contact route with no indication that the original source was water. The frustration of epidemiological studies intended to demonstrate a water source of transmission may be the result of using clinical illness and not index infection rates as criteria. In bathing water and similar studies, the disease rates in secondary contacts might well be a much better indicator of source than the disease rates in bathers themselves. This same principle may hold for bacterial infection and disease, for the main thrust of efforts in this area has always been in the direction of disease and not infection.

Recovery of Small Quantities of Viruses from Large Volumes of Water

Several years ago, we set a tentative standard for ourselves of less than 1 PFU of virus per 100 gallons of water. This standard was based on our assessment that detection of one PFU of virus in 100 gallons of water would be feasible within five years of that time, and not on any conviction that water with less than that amount of virus would be safe. It was our intent to raise our sights if developing technology allowed, and to lower them should a more modest limit need to be imposed upon us.

Clearly, the recovery of 1 PFU of virus from one-hundred gallons of water or more requires exquisite concentration procedures, and many are under study. It is not yet clear which of the several systems presently under investigation will prove the most efficient and utilitarian if, in fact, any one does become universal in all of the several applications for which such methodology is needed. Viruses must be recovered from waters of qualities ranging from raw sewage to completely renovated.

Except in the unusual situation where raw sewage or primary effluents need to be pasteurized or sterilized, only small volumes of such waters need to be tested for viruses because relatively large amounts of viruses are usually present. This is generally true of secondary effluents as well, and in these situations, effective technics, not adaptable to large volume efforts, are already available. The $Al(OH)_3$ adsorption procedure is reportedly capable of recovering 100% of several enteroviruses experimentally added to sewage effluents, but the method leaves most of the large reoviruses and adenoviruses behind. England (16030 DWW) recently reported efficient recovery of experimentally added reoviruses and adenoviruses from effluents by precipitation with protamine sulfate which leaves most of the smaller picornaviruses behind. England uses both methods for maximum recovery of all of these viruses. Protamine precipitation of the larger viruses from $Al(OH)_3$-adsorbed effluents is an important approach today to the effective recovery of viruses from heavily contaminated waters.

The phase separation technic suffers some disadvantage from an overnight time requirement for completion. It has also been reported recently that the method is not efficient with all viruses.

Both the $Al(OH)_3$-protamine sulfate and the phase separation procedures are limited by the volumes they can accommodate, this the result of the large quantities of chemicals required for each unit volume of water tested. When only a few liters or gallons need to be tested, these technics may be considered. When a hundred gallons or more must be tested, other methods must be looked to.

To accommodate large volumes of water, a filtration system seems the best approach. This technic consists of filtering water through 0.45 μ cellulose nitrate membrane filters to which viruses adsorb and from which they can be eluted. For some time now, we have consistently obtained quantitative recovery of enteroviruses and about 80% recovery of reovirus 1. Most of our studies were done with 1-liter samples, but we achieved complete recovery of viruses from 25 gallon quantities as well. With larger quantities of water, recovery has so far been less efficient. In most of these experiments, less than 100 PFU of virus were added to the total volume studied. Most of these experiments were done in distilled water, but several were done in tap water from which we could not always recover viruses quantitatively. As others have reported, certain substances, presumedly organics, apparently can react with the adsorptive sites on the membranes and make them unavailable to the virus. Thus, our immediate goal is to apply the technic to renovated and other clean waters, but it may be necessary to pretreat even such relatively clean waters to remove interfering substances before the membrane filter method can be effectively used for quantitative recovery of viruses. Whether waters of poorer quality can be sufficiently purified without removing or destroying viruses so that such waters can be tested with this technic is still conjecture. However, there is another filtration approach currently in a state of reincarnation that offers promise for quantitative recovery of viruses from water--the ion exchange resin, more voguishly, the insoluble polyelectrolyte. This method consists of filtering water through two Millipore AP 20 fiberglass prefilters between which a Monsanto insoluble polyelectrolyte designated PE 60 is sandwiched. The virus is eluted with 10% fetal calf serum in borate saline at pH 9.0. In our hands, when small amounts of viruses in 1-liter volumes of distilled water were passed through such filters, relatively poor recoveries resulted. Poliovirus 1 recovery in experiments sometimes ranged over 80%, but echovirus 7 recoveries were sometimes somewhat lower than 30% and reovirus 1 recoveries were sometimes lower than 20%. The extent to which the ion exchange resin is affected by water quality is not clear, but apparently, it is less affected than the cellulose nitrate filter.

Nonetheless, we have repeatedly used the technic for virus recovery studies from 50-gallon samples of river water, and repeatedly obtained recoveries. As much as 19 PFU of virus have been recovered from samples taken long distances from outfalls along a large fast-flowing river during the winter months. Thus, despite its low and erratic efficiency at present, the technic appears to be the most sensitive presently available. Since the numbers of different ion exchange resins that can be produced is vast, these substances clearly warrant the reincarnation they now experience.

Other technics including osmotic ultrafiltration and electro-osmosis are also under study, but it is not yet clear what their final contribution to the developing technology will be. Nor is it clear at present whether we will eventually achieve a universal recovery system that can be utilized efficiently with waters of all qualities, or whether we will have to tailor the recovery system to the water under study.

Gerald Berg, Ph.D.
July 7, 1970

ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

DISSOLVED NUTRIENT REMOVAL FROM WASTEWATER

PPB 1701

Division of Process Research & Development
Federal Water Quality Administration
U.S. Department of the Interior

NITROGEN REMOVAL - GENERAL

Municipal wastewaters have nitrogen contents in the 15-25 mg/l range in untreated and primary settled wastes; the nitrogen is divided between organic compounds, which are mostly insoluble, and ammonia. In general, we can depend on conventional biological processes to transform almost all nitrogenous components in wastewater into ammonia and biological sludge. Once this has been accomplished, we can design systems to remove ammonia by air-stripping. Ammonia stripping at high pH in cooling towers following lime treatment is effective but cannot be used during freezing weather and may suffer from serious scale problems.

Under favorable conditions, biological processes may also oxidize ammonia to nitrates by a two-step sequence called nitrification. It would be beneficial if waste treatment plants were required to produce nitrified effluent. Ammonia nitrogen in effluents has several undesirable features:

(1) Ammonia consumes dissolved oxygen in the receiving water;

(2) Ammonia reacts with chlorine to form chloramines which are less effective disinfectants than free chlorine;

(3) Ammonia is toxic to fish life;

(4) Ammonia is corrosive to copper fittings;

(5) Ammonia increases the chlorine demand at waterworks downstream.

A nitrified effluent, free of substantial concentrations of ammonia, offers several advantages:

(1) Nitrates will provide oxygen to sludge beds and prevent the formation of septic odors;

(2) Nitrified effluents are more effectively and efficiently disinfected by chlorine treatment;

(3) A nitrified effluent contains less soluble organic matter than the same effluent before nitrification.

A nitrified effluent is far preferable to one containing substantial ammonia. However, ammonia and nitrate are interchangeable nitrogenous nutrients for green plants and algae, as well as bacteria. If the nitrate level is too high and is helping to stimulate undesirable aquatic growths, the effluent can be further treated by biological action to convert the nitrates to nitrogen gas. This process is called denitrification. The best developed method at this time for control of nitrogen compounds is biological oxidation to nitrates followed by denitrification with the aid of methanol.

Selective ion exchange of ammonia with lime regeneration may be practical but the process is still in the pilot stage. Several other processes are being studied including selective ion exchange of nitrate and chlorination of ammonia to liberate nitrogen gas.

NITROGEN REMOVAL BY BIOLOGICAL SUSPENDED GROWTH REACTORS

Success in providing a high efficiency for nitrogen removal by biological denitrification requires that the biological transformation of ammonia nitrogen to nitrate nitrogen be under good process control. Any reduced nitrogen compounds introduced into the denitrification stage will pass through the process unaltered and impair overall nitrogen removal efficiency.

Complex factors are involved in maintaining nitrification with a conventional activated sludge system. If nitrification occurs at all, it may be due only to an unintentional accident of design. A three sludge variation of the activated sludge process, developed at the Robert A. Taft Water Research Center, greatly simplifies the process control problems associated with maintaining nitrification.

The three sludge system allows management of the separate biological transformations which are necessary for successful denitrification. The three sludge systems are staged in sequence, with flow passing from one stage to the next. The first stage is a high-rate sludge system, the second stage a nitrification sludge system, and the third a denitrification sludge system. The high-rate system handles the bulk of the carbonaceous removal and at this station the waste activated sludge is removed. Thus, the nitrification stage receives a predominantly ammonia nitrogen feed and an enriched culture develops because each sludge system has its own sludge recycle. This process design also has other desirable features. The high rate system protects subsequent nitrification stages from toxic chemicals. Since this is a staged system there can be no direct short circuiting of materials from the influent to the effluent. Temperature effects on the enriched culture of the nitrification stage are not as extreme as with a single sludge system which contains only a marginal population of nitrifying organisms.

Once controlled nitrification has been established, the biological denitrification process can be optimized. The nitrified effluent flows to a slowly stirred anaerobic reactor where methyl alcohol is added in proportion to the nitrate nitrogen concentration. The organisms in this stage use the oxygen component of the nitrate radical to oxidize the organic carbon of methyl alcohol. The end products of this metabolism are elemental inert nitrogen gas and carbon dioxide, which are liberated to the atmosphere.

The stage approach to nitrification has been investigated in work at the Robert A. Taft Water Research Center (1) and in large pilot plant operations at the University of Notre Dame (2) and Manassas, Virginia (3). The process has also been evaluated on a 1 mgd scale at Hazel Crest, Illinois. A summation of these studies show that biological denitrification is a controllable process if the reaction is forced with an organic supplement, such as methyl alcohol. Total nitrogen in an effluent can be reliably reduced to about 2 mg/l. The cost of the methyl alcohol for 20 mg/l of nitrate nitrogen is estimated to be about 2¢/1000 gallons treated. For more information contact:

Mr. E. F. Barth
U. S. Dept. of the Interior, FWQA
4676 Columbia Parkway
Cincinnati, Ohio 45226

Phone: 513-871-1820

References:

(1) Barth, E. F., et al., "Chemical-Biological Control of Nitrogen and Phosphorus in Wastewater Effluent," Jour. Water Pollution Control Federation, December 1968.

(2) Echelberger, W. F. and Tenny, M. W., "Control of Organic and Eutrophying Pollutants by Combined Chemical and Biological Wastewater Treatment," Division of Water, Air and Waste Chemistry, American Chemical Society, Minneapolis, Minnesota, 1969.

(3) Mulbarger, M. C., et al., "Manassas, Virginia, Adds Nutrient Removal to Waste Treatment," Water and Wastes Engineering, April 1969.

NITROGEN REMOVAL FROM WASTEWATERS BY COLUMN REACTORS

Columnar nitrate reduction represents a second alternative to the suspended growth systems as a means of biochemically reducing the nitrate ion to elemental nitrogen. In a packed column, the cell residence time of the surface bound slime is much greater than the hydraulic detention time. This, combined with a large contact surface and short diffusion distances afforded by small media such as sand, provides an efficient system for rapid denitrification of an applied feed.

Work at the FWQA Lebanon, Ohio Pilot Plant (J. M. Smith, 1970, Unpublished) has shown that the smaller media systems (sand to 3/4 inch diameter stone) are effective when operated downflow at surface loading rates of 7.0 gpm/ft and at actual contact times of 50 to 30 minutes. Daily backwashing is required to relieve pressure drop due to the accumulation of suspended solids in the upper portion of the column. The denitrifying slime is firmly attached to the media surface, and is not removed during the backwash operation. Greater than 90 percent nitrate reduction can be achieved within these columns at contact times of 10 minutes for sand and 30 minutes for the 3/4 inch stone. The effluent normally contains less than 2.0 mg/l of nitrate nitrogen with effluent turbidities less than 3 JTU, indicating little solids contribution from the attached organisms.

Larger media varying in size from 1 inch to 2 inch aggregate have been successfully employed to denitrify agriculture subsurface drainage at Firebaugh, California (Tamblyn, T.A., and Sword, B.R., "The Anaerobic Filter for the Denitrification of Agricultural Subsurface Drainage," 24th Purdue Industrial Waste Conference, 1969.) The larger media permits upflow operation without backwashing at the expense of longer contact times and increased effluent suspended solids. Nitrate reduction of greater than 90 percent were achieved in contact times of 1 hour for the 1 inch aggregate and 2 hours for the 2 inch aggregate at temperatures above 12°C. The 2 inch columns have been operated continuously for over six months on agriculture subsurface drainage without the loss of efficiency or solids accumulation.

As with suspended growth denitrification, methyl alcohol is used as the supplemental organic carbon source of choice for columnar denitrification because of its low cost, biodegradability and ease of handling. Approximately 3 mg of methyl alcohol are required per mg of nitrate nitrogen removed including the requirement for deoxygenating the nitrified feed. The chemical cost for removing 20 mg/l of nitrate nitrogen in the presence of 5 mg/l of dissolved oxygen is estimates to be about 2¢/1000 gallons treated. For additional information, contact:

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AMMONIA NITROGEN REMOVAL BY STRIPPING WITH AIR

Ammonia can be removed from a wastewater effluent by raising the pH to convert ammonium ion to dissolved ammonia and then contacting the effluent with a sufficient quantity of ammonia-free air. This physical process is called desorption or, more commonly, "stripping."

If the contacting is done in a packed tower, the pressure drop across the tower is about 1.0 psi or 28 inches of water. Since the volume of air required per unit volume of wastewater effluent is very high, about 400 cubic feet per gallon in a countercurrent operation, the cost for power to overcome even this relatively low pressure drop is prohibitive.

The problem of high power cost was solved by investigators at the South Lake Tahoe Public Utility District (Slechta, A. F. and Culp, G. L., "Water Reclamation Studies at the South Tahoe Public Utility District," Jour. Water Pollution Control Federation, May 1967).who used a slat-filled tower such as is used for cooling water to contact water and air. The pressure drop across such a device is very low, about 1/2 inch of water, so power costs are reduced to reasonable levels. Removal efficiencies as high as 90 percent were obtained in a 24-foot high tower in which wastewater effluent and gas were contacted in a nearly countercurrent fashion. On the basis of this experience, a full-scale stripping tower was constructed at South Lake Tahoe. The tower was designed to remove 90 percent of the ammonia from 3-1/2 MGD of Tahoe's removated wastewater. The air flow is not countercurrent to the liquid but flows across the tower (cross-flow), while the wastewater drips downward through the packing.

Initial operation of Tahoe's stripping tower was in the winter and immediately revealed a limitation of ammonia stripping. When air temperature fell below 0°C,freezing of water occurred at the air inlets, making the tower inoperable. Also, since ammonia solubility is higher in cold water than in warmer water, more air is required to remove it (800 cubic feet per gallon at 0°C). The Tahoe tower was designed for 400 cubic feet per gallon; therefore, removal was much lower than 90%.

Another problem which developed at Tahoe is the formation of scale in the tower. The scale is chiefly calcium carbonate. It forms because the previously lime-treated effluent is supersaturated with respect to calcium carbonate. In the case of the tower at Tahoe, the sludge can be flushed from the tower except from inaccessible areas which cannot be reached with a water jet. A pilot scale ammonia stripping tower at FWQA's Blue Plains, Washington, D. C. Pilot Plant, has had similar scaling problems, except the scale is hard and adheres to the tower fill. The causes of the differences in the nature and amount of scale in various locations has not been resolved. Studies are in progress to see if the scale can be prevented from forming, or if it can be made nonadherent.

The cost of ammonia stripping has been estimated for the South Lake Tahoe facility to be about 2.9¢ per 1000 gallons of wastewater treated. This does not include the cost of the lime and facilities to raise the pH to about 11. These costs have been charged to phosphorus removal because this is the direct objective of the lime addition. If 90% removal of ammonia nitrogen is required even in cold weather, these costs should be increased by about 50% to provide for a higher air-to-water ratio.

Ammonia stripping is feasible when the temperature is above freezing but there is danger of serious fouling by scale. The best approach for minimizing scale and its effects appears to be to use a pH of about 10.5, countercurrent operation rather than cross-flow, and an open fill to allow for easy flushing of accumulated solids. For more information contact:

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NITROGEN REMOVAL BY CHEMICAL METHODS

A. Removal of Ammonia by Selective Ion Exchange

Conventional water softening ion exchange resins which are selective for calcium and magnesium do a relatively poor job of removing ammonium from dilute solutions. Total deionization by mixed bed ion exchange resins will, of course, remove ammonium ions along with other cations but this process is too costly for wastewater treatment.

Certain zeolites show unusual selectivity for the ammonium ion. A number of these have been investigated by the Atomic Energy Commission because they also show selectivity for cesium and potassium ions. A demonstration project at the Battelle Memorial Institute - Pacific Northwest (Hanford) Laboratories, 1969 (Mercer, B. W., et al., "Ammonia Removal from Secondary Effluents by Selective Ion Exchange," Jour. Water Pollution Control Federation, Research Supplement, February, 1970) showed that certain zeolites, including the naturally occurring mineral clinoptilolite, had a high selectivity for ammonium in natural and wastewaters. A trailer mounted demonstration plant with a capacity of 100,000 gallons per day was built as a cooperative demonstration project between the FWQA and Battelle-Northwest. This trailer is now operated under contract to the FWQA to demonstrate selective ion exchange removal of ammonium ions from solution.

Clarified secondary effluent is passed downward through columns containing clinoptilolite. When a column becomes loaded with ammonia, it is regenerated with limewater containing sodium chloride to speed up the rate of regeneration. The high pH of the limewater converts the ammonium ion to unionized ammonia gas in solution. The ammonia laden limewater is then pumped through a packed column through which heated air is blown to remove the ammonia.

Pilot studies at Battelle-Northwest indicated a cost approaching 10¢/1000 gallons for their Zeolite method. At Lake Tahoe, where winters are severe and the area is not readily accessible for chemical deliveries, a cost of 15¢/1000 gallons has been estimated for a 7-1/2 mgd plant. More reliable cost estimates will be available at the conclusion of the present contract with Battelle-Northwest.

B. Ion Exchange for Nitrate Removal

Several attempts have been made to develop selective ion-exchange processes for nitrate removal. Dow Chemical Company is presently under contract to FWQA (Contract No. 14-12-808) to develop a nitrate removal process based on the use of a porous solid absorbent containing a nitrate-selective water-immiscible extractant. The process has the advantages of liquid ion-exchange technology and the ease of operation of the granular bed resin systems.

Selective nitrate removal by ion exchange will not be feasible until new resins are synthesized with a high selectivity for nitrate over other anions present in the water. In addition, a suitable process for treating the nitrate laden regenerants must be developed.

C. Chlorination of Ammonia

Ammonia can be oxidized to nitrogen gas by chlorinating to the breakpoint with either chlorine gas or sodium hypochlorite. Four moles of chlorine or hypochlorite per mole of nitrogen gas liberated are required. Hypochlorite is more expensive than chlorine gas, but it is much safer to transport and handle.

Breakpoint chlorination, of course, also disinfects the wastewater as well as oxidizing ammonia. However, the addition of 200-300 mg/1 of chloride ion would not be acceptable for many inland waters.

Assuming 20 parts of ammonia nitrogen in a secondary effluent, 200 parts of chlorine would be required for breakpoint chlorination. This is equivalent to 1.5 lbs of chlorine per 1000 gallons or about 6¢/1000 gallons. To this must be added the cost of handling the corrosive hydrochloric acid produced. Sodium hypochlorite may cost twice as much as chlorine but associated costs are greatly reduced.

For more information on ammonia removal by selective ion exchange or breakpoint chlorination, contact:

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4676 Columbia Parkway
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For additional information on selective nitrate removal, contact Mr. R. A. Dobbs at the same address.

PHOSPHORUS REMOVAL - GENERAL

Phosphorus is considered by many investigators to be the key nutrient in breaking the eutrophication cycle, However, conventional secondary plants are not efficient in phosphorus removal. Phosphorus enters a plant in the highest oxidized form. But, no common biological systems reduce phosphorus; therefore, it cannot be liberated in a gaseous form as nitrogen, carbon, and sulfur are. Removal by biological means, then, is limited to cell metabolic needs and whatever excess phosphorus can be encouraged to be taken by and stored by the cells. The quantity stored above the 1% required for maximum growth is usually classified as "luxury uptake."

A few plants have reported efficient phosphorus uptake on a sustained basis, including the San Antonio Rilling Plant and the Baltimore, Maryland Plant. These results cannot be readily duplicated at other plants by manipulation of operating conditions. We have not learned enough about the phenomenon to take advantage of it. The removal of phosphorus by biological synthesis and "luxury uptake" is not a controllable process at this time.

If we are to reliably remove phosphorus from wastewaters on a sustained basis, we must choose the chemical or the chemical-biological methods. Strict chemical methods precipitate phosphorus either in the primary settler or in a tertiary clarifier. The chemical-biological method employs direct chemical dosing to the aerator of an activated sludge plant. The chemically-bound precipitated phosphorus is removed with the sludge and is not resolubilized during sludge disposal unless the pH is substantially lowered. Effluent phosphorus concentrations of 1-2 mg/l as P can be regularly achieved if the precipitation is accomplished in the primary or secondary portions of the plant. Tertiary lime clarification followed by filtration will lower the concentration to less than 0.5 mg/l.

BIOLOGICAL PHOSPHORUS REMOVAL

The literature indicates that several factors exert an influence on biological phosphorus removal. The rate of aeration and the aeration time have been indicated by most investigators as the most important criteria, the rate of air supply probably being the more critical of the two. Aeration rates in the order of 3 to 7 cfm/gal and detention times of 4 to 6 hours appear to be desirable.

There is some disagreement in the literature with respect to optimum concentration of mixed liquor suspended solids (MLSS). Apparently, increased uptake has been attained at both low and high MLSS from 500 mg/l up to 4300 mg/l. At the San Antonio, Texas treatment plants, the optimum appeared to be 1000 mg/l or slightly higher (1). It was also found that the maximum overall phosphorus removal occurred at organic loadings of 45 to 55 pounds of BOD/day/100 pounds of MLSS under aeration.

It also appears essential from the literature that a dissolved oxygen (DO) level of at least 2 mg/l should be maintained in the last half of the aeration tank to insure that phosphorus will not be released in the secondary clarifier. It is possible that a still higher DO level of 3 to 5 mg/l may be advantageous to maintain a minimum DO concentration of 1.5 mg/l in the sludge until it is through the secondary clarifier. Phosphorus leakage or resolubilization will occur in the secondary clarifier when the sludge consumes available dissolved oxygen. It has been suggested that solids detention time in final clarifiers should be less than 30 minutes.

These key design criteria and operational parameters have not been sufficiently isolated and identified to effectively predict and implement controlled phosphorus removal by the solely metabolic mechanism. As more data have been collected, an alternative chemical explanation has been advanced (2). Simply stated this theory indicates, especially in hard water areas, that phosphorus can be precipitated within the biological floc as calcium phosphate at the end of the aeration period, where carbon dioxide is scrubbed from the water by aeration and a substantial increase in pH occurs. This amount of precipitated calcium phosphate and the precipitation of additional phosphorus by traces of iron, aluminum, and magnesium normally present in wastewater would produce an efficient overall removal.

The calcium phosphate theory has been tested at several treatment plants with erratic results. Operating a segment of the Hyperion, California Plant according to the guidelines outlined by the theory has greatly increased the efficiency of phosphorus removal. At Baltimore, Maryland where efficient phosphorus removal occurs routinely, observations show no major increase in pH during operation. Studies at Texas City, Texas where attempts were made to deliberately force calcium phosphate precipitation by the addition of 200 mg/l of lime to the aerator have not shown efficient removal.

The preliminary data reported from these full-scale treatment plants are still not complete or detailed enough at this date to confirm either the metabolic or calcium phosphate precipitation theory. For further information contact:

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The University of Texas Medical Branch
Department of Preventive Medicine and
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Galveston, Texas 77550

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References

(1) Vacker, D., et al., "Phosphate Removal Through Municipal Wastewater Treatment at San Antonio, Texas," Jour. Water Pollution Control Federation, May 1967.

(2) Jenkins, D. and Menar, A. B., "The Fate of Phosphorus on Waste Treatment processes: the Enhanced Removal of Phosphate by Activated Sludge," Proceedings of the 24th Purdue Industrial Waste Conference, 1969.

PHOSPHORUS REMOVAL BY MINERAL ADDITION TO THE PRIMARY OR SECONDARY

Mineral addition is out of the research stage and into the application stage. Field experience on full-scale and large demonstration pilot plants shows that ferrous, ferric, and aluminum salts can be equally effective as phosphorus precipitants in wastewater. Plants can accomplish 80 to 90 percent phosphorus removal with a minor investment in capital equipment for chemical storage tanks, chemical pumps, and control equipment (Barth, E. F. and Ettinger, M. B., "Mineral Controlled Phosphorus Removal in the Activated Sludge Process," Jour. Water Pollution Control Federation, August, 1967).

For trickling filter plants, the chemical precipitation should be accomplished in the primary tank. Direct dosing of chemicals to the trickling filter has not proven highly effective. A small dose of polymer is needed to flocculate and settle the phosphorus which is insolubilized by the mineral addition. Subsequent passage through the trickling filter to satisfy metabolic needs serves as a polishing step. Dow Chemical has conducted several studies of iron-polymer precipitation in the primary at Midland, Lake Odessa, Grayling, and Benton Harbor, Michigan. FWQA sponsored projects include Grand Rapids, Michigan (45 mgd) and Richardson, Texas (1.5 mgd). For further information contact:

Mr. Ronald F. Wukasch
The Dow Chemical Company
2020 Abbott Road Center
Midland, Michigan 48640
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With an activated sludge plant, it makes very little difference where the point of addition of themetal ion is. Efficient removals have been obtained when dosing raw wastewater before primary settling, after primary settling, in the aeration tank, or near the mixed liquor exit point. Physical constraints of a particular plant may favor one point of addition over another. However, the key factor in this approach is that no matter where the metal ion insolubilizes the phosphorus, the overall plant efficiency is dependent upon the ability of the biological floc to collect these dispersed precipitates and remove them from the final plant effluent. Polymer addition in the primary is not necessary for an activated sludge plant as the naturally occurring polymeric materials in the mixed liquor will serve the same purpose. FWQA sponsored projects of phosphorus precipitation in an activated sludge plant include Penn State University (2 mgd), Texas City, Texas (0.75 mgd), University of Notre Dame (50,000 gpd), Manassas, Virginia (1 mgd), Xenia, Ohio (1 mgd), and Detroit, Michigan (7,000 gpd). For more Information contact:

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Dosages of 1.5 to 2.0, on a molar basis, of metal ion to phosphorus can produce effluents with a residual total phosphorus of 1 milligram per liter or less consistently on full-scale application. As is true with other parameters such as BOD, COD, and suspended solids, if very low residuals are desired, filtration of the effluent would be required. If commercial aluminum and iron minerals are used, the chemical cost will vary from 2-5¢/1000 gallons, depending on the phosphorus concentration and the chemical employed. If waste pickle liquor is available for the cost of trucking only, the chemical cost may be as low as 0.5¢/1000 gallons.

The mineral addition process can be superimposed on the three sludge biological denitrification process to achieve efficient phosphorus, nitrogen, carbon, and suspended solids removals in one integrated treatment sequence (Barth, E. F., et al., "Chemical-Biological Control of Nitrogen and Phosphorus in Wastewater Effluent," Jour. Water Pollution Control Federation, December, 1968). In this process, the recommended major point of mineral addition is to the high-rate unit with a small polish dose to the denitrification unit to precipitate residual phosphorus.

LIME PRECIPITATION OF PHOSPHORUS

Dorr-Oliver's Phosphate Extraction Process (PEP) is the only commercially advertised lime precipitation process for use in the primary. In this process, a solids contact type reactor-clarifier is used instead of a conventional primary settler. Clarifier underflow solids are recycled to the raw sewage to maintain 500-2,000 mg/l of suspended solids in the reactor. The objective of the PEP process is to achieve 80% phosphorus removal in the primary, depending on the subsequent activated sludge step to increase overall removal to 90% or greater. For further information contact:

Mr. O. E. Albertson
Dorr-Oliver Incorporated
International Headquarters
Stamford, Connecticut 06904
Phone: 203-348-5871

Currently, lime precipitation is also being considered as the first step in a chemical-physical treatment sequence for raw wastewater that does not include a biological unit. Subsequent units in the sequence include lime recovery, filtration, carbon adsorption and possibly ammonia stripping.

The above sequence is similar to the tertiary sequence demonstrated for several years at Lake Tahoe's 7.5 mgd Water Reclamation Plant. The Lake Tahoe Plant utilizes secondary effluent as feed water. Phosphorus removal costs at Tahoe vary monthly from 6-8¢/1000 gal. including amortization, operating costs, and recalcination.

For additional information on chemical-physical treatment of raw wastewater, contact:

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For additional information relative to Lake Tahoe's operations, contact Dr. R. B Dean at the same address.

ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

DISSOLVED REFRACTORY ORGANICS

PPB 1702

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

DISSOLVED REFRACTORY ORGANICS

PPB 1702

PROCESSES FOR ORGANICS REMOVAL

I. Introduction

Most liquid wastes, both domestic and industrial, contain a complement of organics which must be removed or altered before discharge. The classical approach and the method now most widely used has been biological oxidation. Decades of research have produced a great variety of processes, all dependent on biological activity, to consume organics for energy and for cell protoplasm. Biological oxidation has limitations: some organics are not degradeable, toxic materials must be avoided and low temperatures slow biological activity. Recognition of these limitations plus the need to produce increasingly higher quality effluents for discharge or for reuse, led AWT to search for alternatives to biological treatment.

Several processes for removal of organics from both domestic and industrial waste streams are in varying stages of development. These are:

1. Granular activated carbon
2. Powdered activated carbon
3. Adsorbent resins
4. Oxidation processes

II. Granular Activated Carbon

Activated carbon is an adsorbent medium characterized by an extensive system of internal pores which provide it with a very large surface area per unit of weight. This large area plus the variety of functional groups (acidic, basic, oxygenated, etc.) attached to the surface give activated carbon a significant adsorptive capacity for most dissolved organics in wastewater. The carbon, when exhausted, can be reused after regeneration by heating to high temperature (ca 1700^{o}F).

The method of application is primarily determined by the particle size of the carbon to be used. Granular carbon, in the mesh size range from 8 x 30 to 40 x 60, is generally contacted with the wastewater in a fixed or fluidized bed of carbon. Originally, carbon adsorption was considered as a tertiary treatment to supplement biological processes to produce a high quality product of reuseable quality. More recently, the main thrust of research has shifted from the treatment of biological secondary effluent to treatment of clarified raw sewage. Success in the latter effort will provide the sanitary engineer an alternative to biological treatment.

One of the first large-scale applications of granular carbon to wastewater treatment was the South Tahoe Wastewater Reclamation Plant. This 7.5 mgd granular activated carbon plant treats secondary effluent after clarification by lime and mixed media filters. The carbon effectively reduces an influent BOD from 5-20 mg/l to 2-5 mg/l; COD from 20-30 mg/l to 2-10 mg/l; and color from 20-50 to less than 5 units. The average dosage of carbon to accomplish this treatment has been 300 lb/million gallons of treated wastewater.

Large-scale studies at Pomona have substantially confirmed the results obtained at Tahoe. Carbon dosage, however, was found to average about 350 lbs/million gallons. Here, too, effluent quality has been good. Total COD was reduced from 47 mg/l to 9.5 mg/l; color from 30 units to 3 units and turbidity from 10 JTU to 1.6. Significantly the CCE, which has been used as a measure of water quality for drinking water supplies, was 0.014 mg/l, substantially below the recommended 0.2 mg/l.

These two large-scale studies plus bench investigations firmly established that activated carbon can produce effluents with low organic contents and at a cost that is reasonable. To make the process economic it was recognized very early that multiple use of the carbon, in contrast to the single use practiced in water treatment, was necessary. Current regeneration techniques using temperatures of 1600-1700°F plus steam have been able to recover 92-95% of the carbon. Some losses, both physical and chemical, do occur during regeneration. Attempts to regenerate carbon in situ with chemical oxidants or caustic washes have not been successful.

The manner in which the carbon is contacted with the wastewater has been the subject of considerable investigation. The wastewater can be upflow or downflow; the carbon can be static or moved continuously or in slugs; or a fluidized bed can be used. In most of these applications pressure has been used to maintain flows. Simple gravity flow contactors (using lower flow rates) have been suggested as economic. Recent estimates by Swindell-Dressler show that the gravity flow system is less expensive by about 2¢/1000 gallons in spite of the smaller flow rate. Flow rates in pressure systems have ranged 6-10 gpm/ft^2 while gravity flow will range 2-4 gpm/ft^2.

The most thorough estimate of the cost of treating secondary effluent by carbon adsorption was prepared by Swindell-Dressler. Various systems were subjected to side-by-side economic analyses, using data then available in the literature. Total costs have ranged from as little as 8.5¢/1000 gallons for the gravity system to as much as 12.5¢/1000 gallons for a 10 mgd plant.

These studies and others have clearly established that activated carbon can produce good quality effluents from secondary effluent at some reasonable and predictable cost.

A more recent concept in the use of activated carbon is replacement of the biological secondary treatment process in conventional treatment. The process sequence consists of chemical clarification of raw sewage by either organic flocculants or by metal coagulants, when phosphate removal is desired, followed by carbon adsorption. To date, technical feasibility has been demonstrated only at small scale, but full-scale application will be demonstrated within the next two years.

Some impressive information has already been developed on this process which could replace biological treatment by a purely physical-chemical process. Calgon's studies of the treatment sequence (clarification-carbon) has shown the following removals are obtainable when contact time with the carbon is 24 minutes; suspended solids 93%; BOD 93%; COD 81% and TOC 75%. When metal coagulants are used in the clarification step, phosphate removals in excess of 90% can be obtained.

Pilot scale investigations at the Lebanon Pilot Plant of AWTRL have shown that lime clarification followed by carbon adsorption of primary effluent can consistently produce an effluent equal or better in quality than secondary biological treatment. Over five million gallons of primary effluent were processed to produce an average effluent product containing 10 mg/l TOC and BOD with a range of 2-23 mg/l. Effluent turbidity averaged less than 2 JTU and phosphate removals were consistently 90% or better.

Some advantages that can be cited for a physical-chemical process are:

1. Substantially less land would be required. Calgon claims as little as 1/10.

2. Capital costs for conventional plants may be 30-40% greater than that for the P-C plant.

3. P-C process should be less influenced by shock loads, low temperature and by substances which would be toxic to a biological system.

4. The plant should be easy to operate and could be readily adjusted to produce a ranging quality of effluent as desired.

5. Odor problems should be minimal.

6. Significantly, much less sludge will need to be handled. For example, a conventional 10 mgd activated sludge plant will produce about 150,000 gpd of sludge, about 70% of which, or 105,000 gpd, is secondary sludge. The P-C plant could very well reduce the volume to about one-half of the total, depending on the flocculant used, and this sludge should be readily filterable.

A major disadvantage of the P-C process is that ammonia nitrogen will be unaffected. Substantial reductions of organic nitrogen can be expected through solids removal both by the clarification step as well as by the filtering function of the carbon beds.

The plant which will probably be the first to demonstrate the P-C process sequence is located at Rocky River, Ohio. While the original process envisions polymer flocculation, phosphate removal and clarification is being studied for possible use. The carbon adsorption plant will consist of eight pressure contactors, 25 feet high (15 feet of carbon bed) and 16 feet in diameter, and will process a peak flow of 20 mgd (nominal flow of 10 mgd). Flow rate will be 4.3 gpm/ft^2 with a peak rate of 8.6 gpm/ft^2. Carbon will be thermally regenerated at an anticipated rate of 300-500 lbs/day/million gallons. Loss on regeneration is expected to be no more than 5%. Effluent quality objectives are 15 mg/l BOD and 10 mg/l suspended solids, but actual quality may exceed these.

Another plant at Painesville, Ohio, will be designed for a flow of 5.0 mgd, part of which (up to one-half) consists of oil and chemical wastes. Fluctuations of pH from 2-11 and the presence of high concentrations of phenol and chlorine would make biological treatment difficult if not impossible.

Preliminary studies have shown that the wastewater can be effectively clarified (and phosphate precipitated) by ferric chloride. Initial plans call for clarification, roughing sand filters and gravity-flow carbon contactors. The latter will be 15 feet deep, containing 8 x 30 mesh carbon in columns operated in parallel at 2 gpm/ft^2. Effluent quality objectives are, BOD, 20 mg/l; COD, 30 mg/l; phosphates 80% removal and suspended solids 10 mg/l.

Status Summary

The technical feasibility of adsorption of organics by activated carbon has been well established. Regeneration of exhausted granular carbon can be considered to be operational. It remains for the two P-C demonstration plants discussed above to provide operational and cost information. If cost of P-C treatment is comparable to conventional biological secondary and for comparable effluent quality, then increasing numbers of these plants will be used. Reliability of the effluent quality, the smaller land requirements, the freedom from toxic influences, the lack of odor nuisance in areas of population, are some of the reasons why P-C plants will find increasing use.

III. Powdered Activated Carbon

Powdered carbon has developed into a rival of granular carbon. Its finer grain size increases the kinetics of adsorption such that 90% of its adsorption equilibrium is attained in less than 10 minutes. Powdered carbon is dosed in slurry form, after which it is separated by sedimentation following polymer flocculation. Other methods of separation are being investigated. Powdered carbon has the advantage over granular in that its cost is about 1/3 as great. Unit cost and the possibility to control the dosage applied are two of the advantages over granular.

Powdered carbon can be applied to either primary or secondary effluent and is being tested on both feeds. Determination of the technical and economic feasibility must await the results of contracts with Eimco Corp. and Infilco. In contrast to granular carbon regeneration, recovery of spent powdered carbon has been accomplished only in small prototype furnaces. Larger scale regeneration will have to be done before the powdered carbon process is a practical alternative to granular carbon.

IV. Other Methods for Organic Removal

At the present time, powdered and granular carbon provide the reagents of choice for removal of organics. Other methods, however, are being investigated as alternatives to carbon or for specialized applications. Adsorbent synthetic resins are available and newer ones are being developed which have the ability to sorb organics without any substantial inorganic exchange capacity. At this point of development, sorbent resins are not likely to replace carbon but the search for better ones is continuing.

A variety of chemical oxidation methods have been investigated such as chlorine catalyzed by U-V light, metal catalyzed photo-oxidation and ozone. Of these, only ozone appears to be promising. Technical feasibility was established in the laboratory by Airco, Inc., which is currently constructing a 50,000 gpd plant to establish economic feasibility. Because of the cost of ozone itself and the rather large doses, up to 100 mg/l, required for oxidation, application is likely to be limited to treatment of low organic content feeds, such as carbon effluents which need further organic reduction. A valuable benefit of ozonation is its disinfection of the waste stream.

Recent Publications and Reports

Oxidation and Adsorption in Water Treatment Theory and Application. The University of Michigan Dept. of Civil Engineering, Division of Sanitary and Water Resources Engineering, February 1965.

Bishop, D. F., et al., "Studies on Activated Carbon Treatment". Jour. WPCF, February 1967.

Removal of Organic Contaminants. Sorption of Organics by Synthetic Resins and Activated Carbon. Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, University of California, Berkeley, SERL Report No. 67-9, December 1967.

Masse, Arthur N., "Removal of Organics by Activated Carbon". Robert A. Taft Water Research Laboratory, August 1968. (mimeo)

A Comparison of Expanded-Bed and Pack-Bed Adsorption Systems. Robert A. Taft Water Research Center Report No. TWRC-2. December 1968.

Ozone Treatment of Secondary Effluents from Wastewater Treatment Plants. Robert A. Taft Water Research Center Report No. TWRC-4. April 9, 1969.

Nutrient Removal and Advanced Waste Treatment. Robert A. Taft Water Research Laboratory. Symposium on April 29-30, 1969, at Stouffer's Inn, Cincinnati, Ohio.

Appraisal of Granular Carbon Contacting. Phase I Evaluation of the Literature on the Use of Granular Carbon for Tertiary Waste Water Treatment. Phase II Economic Effect of Design Variables. Robert A. Taft Water Research Center Report No. TWRC-11. May 1969.

Appraisal of Granular Carbon Contacting. Phase III Engineering Design and Cost Estimate of Granular Carbon Tertiary Waste Water Treatment Plant. Robert A. Taft Water Research Center Report No. TWRC-12. May 1969.

Rizzo, J. L., and R. E. Schade, "Secondary Treatment with Granular Activated Carbon". Water & Sewage Works, August 1969.

Hager, D. G., and P. B. Reilly, "Clarification-Adsorption in the Treatment of Municipal and Industrial Wastewater". Presented at the 42nd Annual Conference of the Water Pollution Control Federation Meeting in Dallas, Texas, October 5-10, 1969.

Weber, W. J., Jr., C. B. Hopkins, R. Bloom, Jr., "Physicochemical Treatment of Primary Effluents". Prepared for the 42nd Annual Conference of the Water Pollution Control Federation Research Symposium Session, October 7, 1969, Dallas, Texas.

Knopp, P. V., and W. B. Gitchel, "Wastewater Treatment with Powdered Activated Carbon Regenerated by Wet Air Oxidation". Presented at the 25th Purdue Industrial Waste Conference, May 5-7, 1970.

Sources of Information

Much of the research on processes for removal of organics from wastewaters is conducted at or out of the Advanced Waste Treatment Research Laboratory. The address of the laboratory and the principal investigators are given below:

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

JULY 1, 1970

SUSPENDED AND COLLOIDAL SOLIDS REMOVAL

PPB 1703

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

SUSPENDED AND COLLOIDAL SOLIDS REMOVAL

PPB 1703

PROCESSES FOR SOLIDS REMOVAL

I. Introduction

Removal of suspended or colloidal solids from domestic and industrial wastewater is of major importance in any treatment system. Evidence of its importance is the great variety of methods and devices which have been developed for this task. This brief review can only discuss the more widely used processes and describe the newer, more promising techniques now being developed. The subject material can be considered in two parts; the physical aspects which relate to the equipment and the physical methods of solids-liquid separation, and the chemical aspects which involve chemical modifications to facilitate or improve the separation of solids. The principal unit processes employed for solids removal include:

1. Sedimentation
2. Flotation
3. Filtration
4. Microscreening
5. Coagulation-flocculation
6. Miscellaneous processes which include: moving bed filter, ultrafiltration, magnetic separation, ultrasonic flocculation, etc.

II. Physical Processes

A. Sedimentation

The time-honored method for separation of solids involves sedimentation by gravity. In the conventional horizontal flow sedimentation tank, detention periods of 2 to 4 hours are used to enable suspended particles to settle by gravity. It is the simplest of the processes to remove solids, and it is also the least efficient. Colloidal particles settle at such a slow rate that they are not effectively removed. Some degree of short circuiting always occurs leading to lesser detention times for portions of the flow. Because of the inefficiencies of this process many attempts have been made to improve on the separation, still using gravity as the driving force.

One such improvement is the tube settler developed in this country and the Lamella separator developed in Sweden. Both processes achieve separation by causing the particles to settle only inches rather than the several feet as in the conventional settler. This is accomplished by conducting the wastewater upward thru inclined tubes or plates, the solids move toward the lower end of the tubes while the water passes out of the tops. The tube settler has been rather widely used for separation of floc in chemically treated river water. It is also finding application for removal of solids from chemically treated wastewater. There is sufficient information to indicate that this device does separate particles, but insufficient evidence is at hand to conclude that the increased capital investment over conventional sedimentation alone is warranted.

B. Flotation

Another process which separates particles by gravity is flotation. Separation is achieved by attachment of air bubbles, which effectively reduces the specific gravity of the particles to less than that of water. Flotation has found application for clarification of a number of industrial wastes, however, the process is little used at the present time for clarification of domestic wastewater. Its widest application in wastewater treatment is for sludge thickening operations. With additional development, air flotation may find wider application to raw sewage clarification following flocculation by chemical additives.

Air flotation has some attractive potential advantages over sedimentation: 1) a more positive control over the separation rate by controlling process variables such as air/solids ratio or chemical addition; 2) a lower initial capital cost owing to higher separation rates and shorter detention times; 3) reduction of septicity and associated odors owing to aeration of feed and shorter detention times; 4) greater sludge density allowing use of smaller equipment for dewatering;and 5) multiple use of a single treatment unit for removal of heavy grit, suspended solids and oil or grease. These advantages are gained with the following disadvantages: 1) higher operation costs, and 2) greater operational skill is required. The process clearly needs additional research to define in more detail the above advantages and disadvantages.

C. Filtration

Whenever a high degree of clarification is required, then in-depth filtration after chemical treatment is the process of choice. Rapid sand filtration has been practiced for decades by water treatment plants but only recently for wastewater application. In this process, the wastewater passes through a bed of granular media which captures the particles within the filter. When the capacity to store particles is reached, the filter is restored by backwashing. In an ideal filter for downflow operation, the media is uniformly graded from coarse to fine from top to bottom. The usual sand filter does not meet this ideal requirement, hence mixtures of media have been employed to approach the ideal filter. The most common is a two component filter of coal on top of sand. A tri-media filter contains coal, sand and garnet.

One of the difficulties with filters is that the upper layers of the bed become clogged with solids well before storage capacity is reached in the remainder of the filter. Several approaches have been taken to overcome this problem. The filter can be operated upflow in which case the flow proceeds from coarse to fine media approaching the ideal. Some filters have been designed to introduce the feed into the middle of the filter with flow in two directions.

One of the more promising techniques developed by Johns Manville is described as a moving bed filter. The object here is to renew the sand bed surface either continuously or intermittently to avoid surface plugging. This process has been tested at pilot scale and a full scale installation is being made in Manville, New Jersey. Yet another approach has been proposed by the Research Triangle Institute in which a lightweight media floats to form a packed bed. Wastewater is filtered upflow. As the media becomes clogged, it is removed from the bed, washed, and then reintroduced with the wastewater. The concept is sound but feasibility remains to be tested.

D. Microscreening

Microscreening involves straining of wastewater through a woven metal fabric having openings ranging upwards from 23 microns. The screen is continuously cleaned by pressure sprays. Only larger suspended particles are removed since straining is limited to particle sizes greater than the mesh size. These devices have thus far found their greatest application in treatment of river waters. More recently, application to removal of suspended solids from secondary effluents has been tested. Chicago's Hanover Treatment Plant has successfully operated a microstrainer to reduce suspended solids in secondary effluent to less than 5 mg/l. Since about one-half of the residual BOD of secondary effluent is attributable to the suspended solids content, removal of the solids effects a reduction of the BOD as well as suspended solids.

III. Chemical Processes

A. Metal Coagulants

The colloidal components of wastewater cannot be removed by any of the physical processes described above. To remove these solids, the particles must be coagulated and flocculated to larger size before physical methods can be effective. In conventional secondary treatment the colloids are flocculated by organic polymers produced during the biological oxidation. Coagulation and flocculation can also be achieved by chemical additives.

Chemical coagulation and flocculation were first proposed some thirty years ago but was never widely employed. Today, chemical flocculation is the essential first step in physical-chemical treatment. The use of chemical additives has gained impetus from the need to remove phosphates from wastewater, All metal coagulants now being used for phosphate removal also accomplish clarification.

A wide variety of metal coagulants are suitable for clarification (also phosphate removal). These include: aluminum salts, such as aluminum sulfate, and sodium aluminate; iron salts, such as ferric or ferrous chloride or sulfate, pickling liquor which is an iron-containing waste stream from the steel industry; and lime. Which one of the several coagulants to use in any specific instance cannot be predicted beforehand. All metal coagulants are effective and the choice of one from the many has to be made for any application. The choice for any particular application is generally based on relative dosage, the cost of the coagulant and the chemical composition of the wastewater. It is well to remember that to obtain clarification and phosphate removal in wastewater will require substantial dosages of coagulant which in turn will produce chemical sludges which must find disposal. The range of dosages for iron or aluminum salts range 100 to 300 mg/l while for lime the range is 300 to 600 mg/l or more.

In addition to being the first step in physical-chemical treatment, chemical clarification may have some other benefits in solids removal in the primary prior to biological treatment. This concept is being tested at Grand Rapids, Michigan, at full scale. Some of the advantages that may emerge from this are: decreased air requirement in activated sludge resulting from the increased solids capture in the primary; less difficult-to-filter sludge from the secondary while producing more but filterable solids in the primary. And, of course, phosphates will be removed. One of the advantages of lime is that the sludge can be calcined to recover reuseable lime. This has been demonstrated at Tahoe for lime used in secondary effluent and will be applied to lime sludge from raw sewage precipitation at Rocky River, Ohio.

One of the interesting developments of recent years has been the synthesis of a wide variety of organic polymers. Use of organic polymers or poly-electrolytes as sole coagulants or as aids to the inorganic coagulants has added a new dimension to clarification. Very low dosages of polymer may improve efficiency of solids removal, permit reduction of inorganic coagulant dosages and increase settling rates, thus allowing operation of existing equipment at higher flow rates. Dosages range from fractions of a mg/l to several mg/l. Thus, in contrast to inorganic coagulants, sludge volume is not increased. But organic polymers are not a total panacea. They do not remove phosphates, they are all expensive ranging$1-$2/lb for the 100% product, and their behavior for any particular application is unpredictable. The plant operator is faced with selecting a single polymer from the literally hundreds available and even then he cannot be sure that his choice will be effective all of the time. Polymer clarification of raw sewage has been tried at Cleveland's Easterly Plant and at Grand Rapids.

Whether primarily for clarification or for phosphate removal, chemical addition to wastewater is a growing practice. The resulting chemical sludges will pose problems for their disposal.

IV. Miscellaneous Processes

A number of other processes for solids separation are in varying stages of development. One of these is ultrafiltration which is a process akin to reverse osmosis except that inorganic minerals are not removed. The process involves application of wastewater under pressure to a porous membrane. The process cannot compete economically with other solids removal processes for treatment of large volumes of wastewater. But there are special applications for small volume filtration where ultrafiltration may have application. For example thickening of organic sludges or powdered carbon sludge has been investigated.

Another membrane process, called "cross-flow" filtration by the inventor at Oak Ridge, may be useful for solids separation. In this process a membrane is formed on a support and solids separation is obtained under pressures of 30-50 psi.

V. Assessment for the Future

Research of the last decade has provided the consulting engineer with an arsenal of processes for removal of solids. This development comes at a time when, more than ever, better and cheaper ways of solids removal are required. Phosphate precipitation, improved clarification of raw or secondary effluent, and higher quality effluents for tertiary processes have increased the need for separation processes which are more effective and sophisticated than the simple gravity sedimentation now so widely used.

Of the processes discussed here, media filtration, microstraining and chemical coagulation and flocculation are the processes which are now being used. The other processes will be applied as this technology is improved.

Recent Publications and Reports

Rimer, Alan E.
"Filtration Through a Trimedia Filter"
Jour. San.Engng. Div., ASCE, SA 3 (June 1968).

Miller, D. G.
"Rapid Filtration Following Coagulation, Including the Use of Multi-Layer Beds"
Proc. of The Society for Water Treatment & Examination, Vol. 16, Part 3, 1967.

Culp, Gordon
"Secondary Plant Effluent Polishing, Part 1"
Water & Sewage Works, 145 (April 1968).

Ives, K. J., and Gregory, J.
"Basic Concepts of Filtration"
Proc. of The Society for Water Treatment & Examination, Vol. 16, Part 3, 1967.

Diaper, E. W. J.
"Tertiary Treatment by Microstraining"
Water & Sewage Works, 202 (June 1969).

Packham, R. F.
"Polyelectrolytes in Water Clarification"
Proc. The Society for Water Treatment & Examination, Vol. 16, Part 2, 1967.

Smith, R. M.
"The Use of Synthetic Organic Flocculants in the Treatment of Industrial Water and Wastewater"
Proc. International Water Conf., Pittsburgh, Pa., Oct. 1965.

Culp, Gordon
"Chemical Treatment of Raw Sewage, Part 1 and 2"
Water & Wastes Engineering, July 1967 and October 1967.

O'Melia, Charles R.
"A Review of the Coagulation Process"
Public Works, 87 (May 1969).

"Nutrient Removal and Advanced Waste Treatment"
Technical Symposium, Cincinnati, Ohio, April 29-30, 1969
Published by U.S.D I., Federal Water Quality Adm.

Sources of Information

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

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DISSOLVED INORGANIC REMOVAL

PPB 1704

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

DISSOLVED INORGANIC REMOVAL

PPB 1704

PROCESSES FOR REMOVAL OF MINERALS

I. Introduction

During domestic and most industrial uses of water there is added an increment of dissolved inorganic minerals which must be removed if water quality is to be maintained. If recycle of wastewater will be practiced in the future, then almost surely methods will be required to remove inorganic salts. Soluble inorganics are even now a significant problem for many municipalities. For example, a recent survey has shown that of the 20,215 municipal water supplies in the 50 states and 5 provinces in the United States and Canada, 1066 had raw water supplies with a total dissolved solids (TDS) of 1000-3000 mg/l; there were an additional 31 supplies that had a TDS of 300-10,000 mg/l. The rising salinity of many water supplies and the increasing cost of developing alternate sources of better quality make it difficult or uneconomic in many locations to meet the USPHS recommended limit of 500 mg/l TDS for potable water. These factors justify the support for research to develop inorganic removal processes.

Several processes are currently being investigated for reducing the mineral content of municipal wastewater to an acceptable level. These include: (a) ion exchange, (b) reverse osmosis, (c) distillation, (d) electrodialysis, (e) freezing and (f) electrochemical treatment. These processes are in varying stages of development and only the first four mentioned are currently being given serious consideration as practical processes for demineralization.

All demineralization processes produce a brine solution. The disposal of this brine represents a major technical problem in the development of demineralization technology. In coastal areas it may be feasible to discharge brines to the ocean. Solar evaporation in lined lagoons can be employed where climatic conditions are favorable. However, inland areas with limited potential for solar evaporation will require the development of more sophisticated techniques for brine disposal.

II. Ion Exchange

Ion exchangers are materials containing ions that can be replaced by other ions from solution. The replaceable ion carried by the exchanger is known as the counter ion. Carriers of exchangeable cations are called cation exchangers, and carriers of exchangeable anions, anion exchangers. Once all the counter ions are replaced the exchanger is exhausted and must be restored by regeneration with a solution containing the original counter ion.

Ion exchange will almost certainly be an economic process for demineralization of wastewater, if the mineral solids do not exceed 1000-1500 mg/l. This development derives from the commercial availability of new anion resins which have 1) high selectivity for chloride ion, 2) require less regenerant and rinse water, yielding a more favorable ratio of product to feed. But most important has been the discovery that these anion resins do not become "fouled" by organics - the single most important deterrent to ion exchange with the older resins. Up to 50-60% of the COD is removed from secondary effluent with no detectable loss of exchange capacity. The COD is eluted with the regenerant.

Research at AWTRL has confirmed that COD is removed and that fouling does not occur. Studies at the Pomona Pilot Plant facility demonstrated that an effluent containing about 50 mg/l of TDS can be produced from a feed of about 800 mg/l TDS. The bulk of the residual TDS was silica which is not removed by a weak anion resin. Total costs for the process were estimated to be 24¢/1000 gal, excluding the cost for disposal fo the brines. In practice, the product of ion exchange will be blended with good quality, but not demineralized, effluent to provide a product with, say 300-400 mg/l TDS thus yielding a final cost of about one-half of the 24¢/1000 gal cited.

Other cost estimates cited for the DeSal Process (weak anion exchange process developed by Rohm & Haas) have been 18¢/1000 gal for a 1 MGD plant as determined by Rohm and Haas and24¢/1000 gal for a 10 MGD plant estimated by Infilco. Culligan, Inc., is currently investigating several ion exchange processes on a pilot plant scale of 50,000 gpd. Work is also continuing at Pomona and at AWTRL.

The most encouraging work was that done by some Italian workers who came to the following conclusions:

1. The DeSal Process is far superior to conventional ion exchange and makes earlier estimates of cost out of date.

2. Up to 65% of the organic matter is removed and is quantitatively eluted from the resin.

3. After one year's operation no change could be observed on the physical or chemical properties of the resin.

The authors also concluded that ion exchange was applicable to feeds up to 3000 mg/l TDS - a level that we had not generally considered competitive for ion exchange. Of the four methods being considered for demineralization of wastewater, ion exchange will most likely be applied earliest to full scale. The technology is well-developed and the costs appear to be reasonable.

III. Reverse Osmosis

Reverse osmosis is a membrane process in which water is forced to flow from a solution of high salts concentration to one of lower concentration. In natural osmosis, water flows in the opposite direction. Pressures of 600-800 psi are required to obtain this reversal of flow. The earliest applications of reverse osmosis were in the fields of chemical purification and brackish water desalination. The discovery of the cellulose acetate membrane was, perhaps, the single biggest advance in the application of reverse osmosis to desalination.

Membranes are defined as imperfect barriers which "retain" or "reject" molecules of a certain minimum size and will "pass" smaller molecules. The membranes can be tailored to almost any degree of porosity. Several types of materials have been identified as having membrane forming properties suitable for reverse osmosis. Research is continuing on development of more useful membranes.

Cellulose acetate membranes developed for brackish water desalination are relatively tight (i.e. low water permeability) and can reject over 99% of most mineral species. The water flux through these membranes is very low ($\sim$ 10 gal/day/ft^2) and are not economic for wastewater demineralization. Moreover, in treating wastewater, the membranes become "fouled" by dissolved and colloidal organic material leading to drastic reduction in flux. These problems have led FWQA to a membrane development program pointed specifically toward wastewater treatment. Most of the effort to date has been in new membrane development and in methods to control flux decline. The most attractive membranes appear to be modified cellulose acetate types. Current judgment is that the optimum membrane will reject 50-75% of the inorganics and 90% of the organics with fluxes of 50-100 gfd. At the same time substantial effort is being directed toward alleviating the fouling problem. Essentially two approaches are being taken: (a) prevention of fouling by pretreatment procedures or by changes in the hydraulics of the system and (b) cleaning methods once the membrane has become fouled. A promising method for the latter is periodic rinsing of the membrane surface with an enzyme solution. Interestingly, the most effective enzyme solutions have been the common commercial detergent pre-soak mixtures such as Biz.

In addition to membranes an extremely important aspect of reverse osmosis is the hardware. Current modules are of several types and configurations: (a) tubular, (b) spiral wound and (c) hollow fiber. Each of these configurations has its advantages as well as disadvantages, and at this point in development no single choice can be made. All are being investigated concurrently. A recent projection of the economics of RO by Kaiser Engineers compared the configuration as follows:

	sq ft membrane / cu ft equipment	flux gpd/sf	productivity gpd/cf
Tubular	20	32	640
Spiral wound	250	32	8000
Hollow fiber (nylon)	5400	1	5400
Hollow fiber (CA)	2500	10	25000

From this comparison, it would seem that the follow fiber configurations are superior but in practice hydraulic inadequacies may be a serious drawback.

Another approach to reverse osmosis has been entitled "dynamically formed" membranes. In this development, the membrane is formed either from the constituents of the wastewater or from small additions of a variety of additives. The advantage of these homemade membranes is that they can be destroyed and re-formed whenever the membrane becomes fouled. This work is still in the early stages of development.

Reverse osmosis has enormous potential for wastewater treatment. Theoretically, it is conceivable that most components of wastewater can be removed to a high degree in a single unit process. Typical removals that have been obtained are shown in the following table:

Typical Removals from Secondary Effluent
(CA membrane, 450 psi, ~ 8 gfd)
% rejection

TOC	90	Phosphate	94
TDS	93	Nitrate	65
Turbidity	99+	Ammonia	85
Alkalinity	90	Organic Nitrogen	86
Chloride	80-85		

The practical achievement of the above theoretical capability must await the solution of some serious problems, among which are: membrane fouling, membrane cost, greater (and therefore economic) fluxes, and reduction of operating costs. On the latter, the best estimate is on the order of 40¢/1000 gal projected for brackish water desalination. Because of the potential of this process, research on all of the problems is being pursued vigorously.

IV. Distillation

Distillation is now the most commonly practiced method for obtaining fresh water from sea water. Today there are 90 million gallons per day of plants in operation or under construction in various parts of the world, and this capacity is being expanded rapidly. As everyone knows, distilled water is a common synonym for pure water, hence it is not surprising that distillation is being considered for wastewater treatment and renovation. But distillation of wastewater is substantially different than distillation of sea water. Preliminary studies have revealed that some treatment of the distillate (product) will have to be practiced to remove volatile substances. It is also likely that the solids and organics in wastewater will pose additional problems. All of these aspects are being pursued.

V. Electrodialysis

Another membrane process for demineralization is electrodialysis, but, in contrast to reverse osmosis which uses pressure as the driving force to separate water from minerals, the energy in this case is electrical. A direct electric voltage applied across a cell containing mineralized water will cause the cations to migrate to the negative electrode and the anions to the positive electrode. If cation and anion permeable membranes are inserted between the electrodes, then mineral ions can be separated from the water. Characteristically, 40-50% of the dissolved salts can be removed in a single pass through an electrodialysis stack.

The technical feasibility of electrodialysis has been demonstrated both for brackish water desalination and wastewater demineralization. But, as with reverse osmosis, membrane fouling by wastewater solids and organics has deterred practical application. The process is being investigated at both the Lebanon and Pomona pilot plants of AWTRL. Emphasis of the research is on controlling the membrane fouling by intensive treatment of the feed and by enzyme flushing of the membrane surfaces. The process could be economically attractive once the fouling problems can be solved since cost, exclusive of brine disposal, has been estimated to be 15-20¢/1000 gallons.

Assessment for the Future

Almost surely, increasing parts of this country and the world, will look to their wastewater as an additional source of water resources. And just as surely, some form of demineralization will have to be applied to reduce mineral salts. At this time, no single process, of the several being studied, is ready for full-scale application and no single process has a clear and obvious advantage over the others. However, ion-exchange, because of its highly developed technology in other fields, appears to be the process which will find earliest application. A modest breakthrough in reverse osmosis could find this process applied, particularly to certain industrial waste streams. It bears repetition that a suitable method has to be found for disposal of the brine concentrates from any demineralization process.

Recent Publications and Reports

Eliassen, R., Wyckoff, B. M., and Tonkin, C. D.
"Ion Exchange for Reclamation of Reusable Supplies"
JAWWA, 57, 1113 (Sept. 1965)

Sturla, Piero (Rome, Italy)
"Pilot Plant Studies of the Kunin Process"
Paper presented at International Water Conf., of The Engineer's Society of Western Pennsylvania, September 30, 1964, Pittsburgh, Pa.

Pollio, F. X., and Kunin, R.
"Tertiary Treatment of Municipal Sewage Effluents"
Environmental Science & Technology, 2, 54 (Jan. 1968)

Parkhurst, J. D., Chen, C., Carry, C. W., and Masse, A. N.
"Demineralization of Wastewater by Ion Exchange"
Paper to be presented at 5th International Conf. on Water Pollution Research, August 1970, San Francisco, California.

Kraus, K. A., Shor, A. J., and Johnson, J. S. Jr.
"Hyperfiltration Studies X. Hyperfiltration with Dynamically-Formed Membranes"
Desalination, 2, 243 (1967)

Hindin, E., and Bennett, P. J.
"Water Reclamation by Reverse Osmosis", Water and Sewage Works, 66 (February 1969)

"Study and Experiments in Waste Water Reclamation by Reverse Osmosis"
Final Report - Gulf General Atomic - Contract 14-12-181 prepared by
I. Nusbaum, J. H. Sleigh, Jr., and S. S. Kremen

"Engineering & Economic Evaluation Study of Reverse Osmosis", F. L. Harris, Kaiser Engineers, Presented at Office of Saline Water 2nd Symposium on Reverse Osmosis, (April 1969)

Merten, U., and Bray, D. T., "Reverse Osmosis for Water Reclamation" Presented at 3rd International Conf. on Water Poll. Research, Paper No. 15 (1966).

Cooke, W. P.
"Hollow Fiber Permeators in Industrial Waste Stream Separations"
Desalination, 7,31 (1969/70)

Brunner, C. A.
"Pilot-Plant Experiences in Demineralization of Secondary Effluent using Electrodialysis"
JWPCF, 39, R1 (October 1967)

O'Connor, B., Dobbs, R. A., Villiers, R. V., and Dean, R. B.
"Laboratory Distillation of Municipal Waste Effluents"
JWPCF, 39, R25 (October 1967)

Sources of Information

Much of the research on processes for removal of minerals from wastewater is conducted at or out of the Advanced Waste Treatment Research Laboratory. The address of the laboratory and the principal investigators are given felow:

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

DISSOLVED BIODEGRADABLE ORGANICS REMOVAL

FROM WASTEWATER

PPB 1705

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

PURE OXYGEN AERATION OF ACTIVATED SLUDGE

Linde Division of Union Carbide, under contract to FWQA, has completed a comparison of pure oxygen aeration and air aeration in the conventional activated sludge process. The study was carried out in identical parallel trains at the 2.5 mgd Batavia, New York plant. Inefficient utilization of costly pure oxygen has discouraged similar full-scale operation in the past. The covered-staged oxygen injection and dissolution concepts developed by Linde overcome this obstacle and 90-95% utilization of the input oxygen was achieved.

The oxygenation system used employed sealed covers on the aeration tanks and intertank baffles to form a series of staged compartments. Each compartment or stage is equipped with a submerged turbine-rotating sparger unit and a recirculating gas compressor located on the top of the tank cover.

The three points demonstrated by this study with the greatest potential for reducing the cost of waste treatment are:

1. The substantial reduction in aeration volume possible with oxygen aeration while maintaining efficient carbon and solids removal. The oxygen train achieved better treatment in 1-1/2 hours aeration detention time than the air train at 3 hours.

2. The high solid content of the waste activated sludge achieved by the oxygen system; thereby, possibly eliminating the need for a separate thickener operation. Oxygenated sludge had a Sludge Volume Index of 40 and concentrated to about 3% in the final clarifier underflow.

3. The reduced quantity of waste sludge produced with oxygen. Significant reduction in the quantity of waste activated sludge produced by the oxygen system was noted. The best estimates at this time are that the reduction, by weight was 30-40%. Better data on the exact amount will be obtained this summer.

The economic substitution of pure oxygen for air may eventually prove to be one of the most significant breakthroughs in the history of the activated sludge process. The pure oxygen process, in addition to offering potential reduction in new plant construction, is also applicable to many existing high-rate or overload plants which are performing poorly.

For more information, see report "Investigation of the Use of High Purity Oxygen Aeration in the Conventional Activated Sludge Process" by Linde Division of Union Carbide Corporation, Contract No. 14-12-465, or contact:

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TRICKLING FILTERS

There has been no major breakthrough in the past two years. This process is capable of producing a good quality effluent having a BOD_5 of less than 20 mg/l if lightly loaded. In the United States, the tendency is to load the filter at a much higher rate than is done in England. Thus, we find today many installations that will have difficulty in meeting the more stringent water quality standards.

It is not enough to just look for completely new processes, but attention and action must be given immediately to applying known technology to upgrading present treatment plants. All the needed new plants and plant expansion cannot be built in a short time. Substantial amounts of pollution can be prevented from reaching our surface waters by upgrading present plants. There are several ways of achieving higher removals. There is probably no one solution that will work at all installations, for each plant is different. If a plant is not getting good removal and the impairment is not due to toxic or grossly atypical waste, then it is usually due to either hydraulic overload, organic overload, or poor final liquid-solids separation. The following are suggested ways of alleviating these conditions.

Easing hydraulic overload

1. Find and reduce needless sources. Infiltration, downspouts, and cross connection can contribute greatly to the flow.

2. Use large interceptors as holding tanks. Many towns use their main interceptor to the plant to back-up the flow during the day and treat it at night when the flow is low.

3. Construct an equalizing or surge tank to smooth out the high peak flows. An equalization tank will mix and dilute toxic wastes, giving better downstream settling and lessen load fluctuations.

Aiding organic overloaded plants

Most organically overloaded plants can be aided by the same methods suggested for hydraulic overloads since they commonly occur concurrently. Additional methods are:

1. Have industry program the load for slow release. In smaller towns, most industries are willing to program extremely high organic waste flows.

2. Have industry treat at source using a roughing filter or other appropriate means to relieve part of the load.

3. Treat digester supernatant return by alternate methods or program return load to time of low load.

4. Remove more material in the primary tank by using iron or aluminum salts and polymers in the incoming waste. This will also remove phosphorus.

Lessen final solids discharge

One of the greatest improvements that can be made in secondary treatment is reliable solid removal from effluents. For efficient overall removal, the final settler must remove better than 98% of the solids. If overflow weirs are submerged several inches with the present flow, then there is no recourse except to increase settler capacity. For less hopeless cases, the following can be tried.

1. Chemical flocculation or precipitation in process or final effluent treatment.

2. Improve inlet and/or overflow design.

3. Install a microscreener.

4. Install mixed media filters.

5. Install tube settlers.

If a town has a trickling filter that is water tight or can be made so, the filter unit can be simply converted to an aeration tank. This can be done by removing the filter media and installing a surface aerator. The existing primary and final clarifiers can be utilized with minimal structural and piping changes. This type of conversion will usually increase the capacity of the plant twofold for a fraction of the cost of a completely new plant.

All the methods discussed are not new, but are well-proven processes. Thus, there are answers to the question on how a town can meet the new water quality standards. All that is needed is an awareness of the fundamentals involved and a willingness to pay for and use all the technology that is known.

ROTATING BIOLOGICAL DISCS

The rotating biological disc method of treating waste has been used in Europe for at least the last five years. The system basically consists of closely spaced rotating discs alternately submerged in wastewater and exposed to air. Wastewater continuously flows parallel to the discs. The waste level is slightly less than half the disc diameter. The units are usually arranged in series or stages.

The discs are molded of low-density expanded polystyrene. The entire downward load is offset by the buoyancy of the discs. Thus, the only power required to rotate the discs is that needed to overcome bearing friction. Microorganisms attach themselves to the discs and perform the same function as in a trickling filter. The biomass sloughed off the discs is removed in a final clarifier. In short, the rotating biological disc method is a modern version of the "Immersion Filter" developed by Buswell in the middle twenties.

FWQA has funded a grant (1701 EBM) with Rutgers University to assess the degree of treatment and to obtain operating data on this method of treatment. The pilot plant used in this study is a ten-staged unit with a design flow of 8 gpm. This gives a detention period of 5 minutes per stage or a 50-minute overall detention time for the disc unit. The plant has been in operation for about one year at the Jamaica Treatment Plant in New York City near the Kennedy International Airport. Data obtained thus far show that the unit is oxidizing about 93% of the biodegradable carbonaceous matter and 80% of the ammoniacal nitrogen in the primary effluent being treated. A report on the work is not available at this time.

A demonstration grant (11010 EBX) has been awarded to the Village of Pewaukee, Wisconsin to evaluate the effectiveness and efficiency of the rotating biological disc method for treating municipal wastes on a full-scale community level. The performance of the unit will be compared directly with an existing trickling filter under identical conditions. The design flow of the disc unit is 0.46 mgd. The unit is scheduled to be on-stream the latter part of this year.

The rotating disc system has an advantage over a trickling filter unit in that recycle is not necessary at night to keep the biological mass wet because the trough always contains liquid. It seems quite possible that the method can produce an effluent in quality some place between that of a trickling filter and an activated sludge unit. It is conceivable that the system would find application at some of our Federal installations, such as small parks or rest stations where there is a wide variation in the flows. There is a small two-stage unit available that handles population equivalents of 12 to 200 persons.

The main disadvantages of the method are that it must be housed to protect it from storms, hail, etc. and the large disc surface area required. For 90% removal, the unit load is 2.7 gal/day/ft^2 of disc surface area. Normally the discs are ten feet in diameter and the disc spacing is 0.846 inches.

Instrumentation and control have not yet caught up with the basic requirements of wastewater plants. There are several reasons for the limited use of continuous automatic analysis and control. Some of these are the absence of sensors to measure some of the most important factors directly, the fairly high cost of instruments available, and the willingness of those in the waste treatment field to decide that automatic operation is necessary and to take all the steps required to bring it to fruition. In the past, the cost of instrumentation has eliminated them from consideration by managers of small and medium-sized plants.

Recent emphasis on water quality standards is bringing about a natural increase in the extent of automatic control. This is especially evident in newer facilities where instrumentation is no longer an "afterthought", but an integrated part of plant design. Unfortunately, some engineers engaged in designing new plants have not kept up with the improved processing techniques. The design of a modern plant for treatment of wastewater requires a considerably broader knowledge of treatment and control techniques than in the past.

Many sensors cannot be used in treating wastewater because they become fouled by the gross solids, greases, oil, and aquatic growths. Despite the encumbrances inherent in the physical makeup of raw wastewater and sludge drawoff, measuring devices and instrumentation are now available that can monitor and control most of the secondary plant flow systems. The real problem in automating the various flow regimes is not a lack of flow controlling equipment, but the inability to rapidly measure biological activity or "state-of-health" of the system. For instance, wasting of activated sludge could logically be based on the active mass of microorganisms in the system. However, the closest we can come now to determining active mass is mixed liquor volatile suspended solids and this has been estimated to represent 50 to 100 percent more active solids than are actually present. Thus, the difficulty in controlling the treatment plant is directly attributable to the inability to model constantly changing life processes.

It would appear that the best index for understanding and controlling the activated sludge process would be the amount of living cells in the aeration tank. No method now exists which permits determination of the microbial activity in a manner useful to process control. Adenosinetriphosphate (ATP) is present in and essential to all living cells. Measurement of ATP would be a rapid and unequivocal method for active microbial mass. Biospherics Incorporated is under contract (14-12-149) to design and fabricate an instrument for use in the ATP assay. In addition, they will adapt the firefly bioluminescent method to determine the ATP of activated sludge which is directly proportional to the biomass. E.I. DuPont is now producing commercially the reagents needed for the test; therefore, there will not be any difficulty in obtaining the reagents if the method becomes a reality. This method probably can be automated. The time to perform the tests should be about 15 minutes if done manually.

Biological process efficiency is now measured by various laboratory analytical techniques. The time required to collect, transfer samples, and perform the analyses may take anywhere from three hours to five days. The time involved in obtaining data seriously hinders rapid and effective process control. On-line instrumentation designed to yield reliable, useful information in terms of minutes instead of hours would contribute significantly to improving plant operation. Contracts are now being let to develop an on-line instrument to measure the organic strength of influent and effluent streams at a waste treatment plant. The instrument will be capable of analyzing both filtered and unfiltered samples. This will entail developing an on-line macerating device as well as an on-line filter. Within the next year, it is hopeful that a full automatic on-line COD and TOC analyzer will be available to treatment plants.

A wastewater treatment plant can have too much instrumentation and automation or it cannot have enough. Most wastewater treatment plants now have too little instrumentation to give adequate control. The new pilot plant at AWTRL in Cincinnati will test new process control equipment and instruments in the coming year. The aim here is to operate them under controlled conditions to determine durability, performance, and limitation. This information will then be made available to construction grants people and consultants so that new plants can be operated more efficiently.

ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

MICROORGANISMS REMOVAL FROM WASTEWATER

PPB 1706

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

Introduction

In this first annual report covering the status of disinfection of wastewater and AWT treatment plant effluents, it is believed that a look at where we stand now and what is planned for the future should provide a better understanding of what may be expected from this subprogram.

Present Status of Chlorination

The most desirable objective is to be able to say that application of a specified dose of chlorine would provide safe disinfection of all effluents. The coliform test should be considered the primary standard; the chlorine residual can only be considered as a secondary standard and it is only valid to the extent confirmed by the results obtained in the coliform test. The conclusions of Browning and McLaren (Jour. Water Poll. Control Fed., August 1967) indicate the problems of operating on a basis of a specified combination of chlorine residual and contact time. They state "Generally speaking, a correlation exists between chlorine residual and coliform density (coliform densities decrease with increased chlorine residuals) but the individualities of waste treatment plants and their effluents make it difficult to apply a correlation determined from one plant to other plants." Each plant must develop its own data for correlating chlorine dosage, residual, and contact time to yield predictably the desired reduction in coliform count.

The most highly clarified and oxidized effluents are the easiest to disinfect. If good control of microorganism content is to be attained by chlorination, good secondary waste treatment should be the minimum. Chlorination of primary effluents should not be considered an acceptable practice in most situations except as an interim process until secondary treatment facilities can be constructed.

Some concern has been expressed regarding the fact that numerous viruses are more resistant to chlorine than the coliform bacteria. Methods of using viruses as an indicator of chlorination efficiency have not reached the stage where practical tests for routine use are available. The coliform test still remains an effective criterion for disinfection of drinking water. Except for hepatitis, clearly defined outbreaks of virus diseases traceable to drinking water have not been reported (Clarke, Berg, et al., Adv. Water Pol. Control Research, Pergammon Press, McMillan Company, New York, Vol. 1, 1964). Epidemics of hepatitis originating in chlorinated water supplies judged satisfactory by the coliform test have not been reported except in instances where obvious deficiencies in chlorination were shown or suspected. It is not, therefore, considered likely that effluents disinfected to satisfactoy coliform destruction levels are much of a health hazard. FWQA has funded a grant (69-G385) to investigate the possibility of locating a new bacterial indicator that is sufficiently more resistant than coliform organisms to provide a safety factor for virus destruction. The emphasis is on the discovery of an organism that can be enumerated by simple plate count or MF procedures.

Status of Research

Because of personnel limitations and other problems, research in the disinfection program has been limited in scope thus far. The outlook for the future is improving and a marked increase in the number and variety of grant and contract projects is anticipated in FY 1971.

In-House:

There have been numerous reports in the literature of a major synergistic effect of gamma radiation on the disinfecting action of chlorine, but the work reported has not been adequately controlled. An investigation to determine whether gamma radiation exerts a synergistic effect on the disinfecting action of chlorine is now in progress. This work is being done under very carefully controlled conditions. Present progress indicates that this project will be completed in FY 1971, and it is anticipated that definitive data will be produced to either support or negate the existence of a synergistic effect.

Grants:

Grantee	Subject	Project Director Expected Comp. Date
Illinois State Water Survey, University of Illinois, Urbana, Illinois.	Disinfection of Sewage Effluents with Chlorine and Bromine.	Dr. F. W. Sollo 9/30/70
City of St. Michaels St. Michaels, Maryland. (Clow Waste Treatment Division Aer-o-Flo Yeomans, Melrose Park, Illinois Engineering Operator for Grantee)	Controlled Treatment System-Ultraviolet Disinfection.	John A. Roeber 7/9/70
University of Illinois Urbana, Illinois	New Microbial Indicators of Wastewater Disinfection.	Dr. R. S. Engelbrecht 9/30/71

Much of our research in disinfection of wastewater deals with problems related to the use of chlorine. Chlorine, however, is not necessarily the answer to all of our disinfection problems, and little information is available regarding the use of other disinfectants for the destruction of microorganisms in wastewater. Other disinfectants are, therefore, being investigated. The program is planned to develop, as rapidly as possible, methods for the use of a variety of disinfectants and provide guidelines for their practical application. The rationale for this approach is to make available to the sanitary engineer a spectrum of proven disinfection processes from which he can select the one most applicable to a specific waste treatment disinfection problem.

Research Statements of Need

The extent to which the Disinfection Subprogram can satisfy the needs of the respective Regional Programs depends upon how well we can identify those needs and formulate work programs to satisfy them. Satisfaction of those needs can best be expedited by good liaison with the Region. It would be most helpful if the Regions would submit statements of research needs to cover specific problems in need of solution. The development of an adequate research work plan to satisfy a particular need, however, depends upon the content of the need submitted. This can best be accomplished through a preliminary discussion of the proposed need by the Program Chief and the proponent.

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

ULTIMATE DISPOSAL

PPB 1707

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

THE ULTIMATE DISPOSAL RESEARCH PROGRAM

at the

Robert A. Taft Water Research Center
Cincinnati, Ohio

The Ultimate Disposal Research Program is responsible for finding places to put the pollutants which have been extracted from waters by conventional and Advanced Waste Treatments. Disposal of residues must of course be done in ways that will not cause pollution and ideally the residues should be reused to the maximum extent possible. Our responsibilities cover disposal to the air, waters, and to the land, as well as reuse and recycling of constituents. Control of pollution of underground waters is a specific assignment of the Robert S. Kerr Water Research Center, but general considerations of deep-well disposal are also reviewed here. Deep-well disposal is not a generally applicable method and should be used only where the local geological formations are particularly favorable and there are no acceptable alternative methods for disposal.

Disposal of wastes is the most frequently neglected part of our modern industrial civilization, and is directly responsible for our polluted planet. Attention to unit operations, with little regard for the fate of by-products which are no longer interesting and are frequently embarassing, has produced the present situation. In an attempt to focus attention on disposal problems, and to reduce some forms of pollution at their sources, a number of papers have been published calling attention to valid and invalid disposal methods (see Bibliography).

Disposal of organic sludge from conventional wastewater treatment plants accounts for up to 50% of the total costs of treatment. Disposal of sludge requires removal of the water content which accounts for 95 to 99.5% of the weight, followed by storage of oxidation of the organic matter. Since activated sludge has a much lower solid content than primary sludge, the addition of secondary treatment greatly increases the sludge disposal problems of the plant. Equipment which was effective for primary sludge frequently proves to be inadequate when waste activated sludge is added. The current FWQA policy, requiring secondary treatment for most large plants discharging to inland waters, will greatly magnify the sludge disposal problems in this country.

Incineration can be accomplished in modern equipment without producing pollution of the air or water. An outstanding example of pollution-free incineration may be seen at the South Lake Tahoe Advanced Waste Treatment Plant (see "Product Recovery" in attached list of contracts). At Lake Tahoe, organic sludge and lime sludge are separately incinerated in two incinerators which produce absolutely no plume or odor. It is impossible to tell from outside the plant whether the incinerators are working or not.

The cost of incinerating sludge is directly dependent on the water content; therefore, efficient dewatering is the key to efficient incineration. Present dewatering techniques include sedimentation, vacuum filtration, pressure filtration, and centrifuging. All of these techniques are being examined in full-scale equipment under demonstration grants. There are a number of chemicals which aid dewatering, including lime and salts of iron and aluminum, as well as synthetic polymeric flocculants. A limited amount of laboratory work is devoted to evaluation of available products, but it is recognized that field experience provides the most usefuly information. Radiation, freezing, pressure cooking, treatment with enzymes and the addition of sludge ash have all been proposed as useful aids to dewatering. Both radiation and freezing have turned out to be too expensive for the benefits achieved. Pressure cooking with or without the addition of oxygen is being evaluated at Colorado Springs, Painesville, Ohio and Santee California. Pressure filtration with ash is being evaluated at Cedar Rapids, Iowa, and vacuum filtration has been studied in the laboratory. A contract for the development of enzymes to thicken sludge has been underway at Aerojet-General.

Land disposal of sludge without previous dewatering is particularly attractive, since it uses a low cost filter, the earth, and low temperature oxidation by microorganisms. Although larger quantities have to be transported when the sludge is not first dewatered, the transportation can be done economically by pipeline. A recent contract with Bechtel, Inc. appraises the cost of pipeline transport of sludges for the case of Cleveland, Ohio, but can be applied to many other situations. Land disposal of sludge if properly operated is true conservation of resources and recycles essential elements to the biosphere. On low grade land, sludge improves fertility and enhances the value of the environment. Political objection to other people's "sludge" and a natural aversion to old fashioned smelly sewage farms has held back rational utilization of the land for sludge disposal even though its cost may be as low as one fourth of that for drying and incineration. Papers have been published and talks given to point out the advantages of land disposal. Greenhouse and field plot studies are underway, both in-house and under grants, to improve our knowledge of land disposal. A recent workshop at Chicago reviewed the state of the art of land disposal and an excellent summary has appeared in the May 16, 1970 issue of the Prairie Farmer.

There are valid objections to land disposal of sludges, particularly if they are improperly applied. Excessive loadings of sludge can contaminate ground water and in some situations it may be necessary to collect and treat water from underdrains as it is done in major irrigation projects. Nitrates are apt to be the principal pollutant, just as they are with irrigation. There is little evidence that the soil will be poisoned by excessive quantities of organic matter or by heavy metals in the sludge, if proper care is taken. Pathogens can be controlled by pasteurization if necessary, or by long holding periods in lagoons. Even without these protective measures there have been no reports of sludge born disease since 1919, despite widespread application of sludge to farm lands in this country and in Europe. Studies of pathogen survival in soil are underway.

Sludge can not be stored without some form of stabilization to prevent putrefaction and the development of objectionable odors. Anaerobic digestion is a reasonably well understood process that causes a great deal of difficulty, particularly when practiced on a small scale. Aerobic stabilization is potentially capable of destroying nitrogen compounds and appears to be an ideal pretreatment for land disposal. The process is poorly understood, and the costs of aeration are high. Some in-house work on aerobic stabilization has been carried out and we are looking for a suitable contractor to investigate this process further. Treatment with lime is an attractive alternative to digestion preceding land disposal.

Petroleum wastes represent an interesting application of land disposal. Despite common knowledge that oil "kills the soil", well-oxidized soil will destroy up to 12 inches of petroleum by-products in a year under favorable conditions of temperature and humidity, provided that the soil is kept well-aerated (Dotson, et al., 1970).

Industrial sludges frequently consist of soil minerals such as calcium, carbonate and sulfate and oxides of iron and aluminum. There minerals can be incorporated into the soil in substantial quantities without destroying the agricultural value of the land. In all applications of wastes to the land it is necessary to have good farm management, and not to treat the land as a dump.

The land treatment of sewage is of interest for small communities. This process is frequently referred to as the "living filter". Extensive work on this application has been done at Pennsylvania State University and by several food processes. We have recently received a number of proposals for grants to use the "living filter" treatment for phosphate removal in the Great Lakes area.

Disposal to the atmosphere should be limited to gases which are naturally present. In addition to nitrogen, oxygen, water vapor, and carbon dioxide these include ammonia, nitrous oxide (N_2O), and products of combustion such as higher oxides of nitrogen and sulfur. The last two groups are well-recognized air pollutants, but are contributed in insignificant quantities by well-operated incinerators. Nitrous oxide is remarkably inert and is probably not an air pollutant. Ammonia is rapidly absorbed by moisture and vegetation and reacts with the oxides of sulfur, preventing formation of sulfuric acid. It could be an objectionable nutrient if released upwind of a large body of water, but it could reduce air pollution in some industrial areas. We are studying the removal and destruction of ammonia under a contract with Battelle-Northwest.

Conversion of nitrates to nitrogen gas by dilute solution reduction has been the subject of another contract which is being brought to a close. The process does not appear to be practical for municipal effluents but may be useful for certain industrial wastes.

Brine disposal can contribute a significant part of the cost of water renovation in inland areas. The problem of brine disposal at three major western cities is being evaluated under a contract with Burns and Roe. If salt water lakes or playas are not available, it may be necessary to evaporate the bulk of the water and transport the remaining slurry to a salt-water area. Evaporation ponds appear to be the best solution in arid areas where desalting is most necessary. A small evaporation pond study is being carried out as a part of our cooperative research program with LACSD at Pomona. We are currently regotiating a contract to evaluate the potential of cooling towers for evaporating bring solutions, particularly in high rainfall areas.

Recovery and reuse of the chemical values in sludge is esthetically attractive, but only in rare cases are sludges attractive sources of raw materials for other operations. Utilization of sludge to increase the agricultural value of land is, of course, one form of reuse which is economically attractive. At the other end of the scale, although sludge is a good source of Vitamin B-12, extraction of this substance does not significantly reduce the problem of sludge disposal. The sale of dried sludge for agricultural purposes at Chicago defrays only a quarter of the cost of drying sludge. Recovery of chemicals used to treat sewage or sludge is seldom able to pay the cost of recovery. Lime recovery at Lake Tahoe is probably no better than a break-even proposition; however, it reduces the sludge disposal problem significantly. We are investigating under contract possible markets for the phosphate-rich fraction of the recovered lime which would otherwise be disposed of in a land-fill. In-house studies of aluminum recovery from sludges containing aluminum that was used to remove phosphates indicate that in most situations the recovered aluminum salt would cost more than new chemical; however, the recovery process greatly improves the dewatering qualities of the sludge and may be economical from that point of view. We have also found that recovered lime is superior to fresh lime on a calcium hydroxide basis when used for phosphate removal. The recovered lime produces sludges which are easier to filter and centrifuge because of the presence of inert filter aids formed by the ash.

A small contract has studied the recovery of amino acid values from sludge and their utilization as animal feed. Activated sludge is essentially a form of single-cell protein containing, unfortunately, substantial quantities of undigestible matter. If the nutritive amino acids and sugars can be economically separated from the undigestible fraction, it should be possible to make a valuable feed supplement (Dean and Bouthilet, 1970).

Attached is a list of references to pertinent publications from the Ultimate Disposal Program and a list of contracts dealing with significant aspects of our work.

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PUBLICATIONS

Ames, L. L., Jr., and Dean, R. B., May 1970. "The Use of Alumina Columns for Phosphorus Removal from Secondary Sewage Effluents," J. Water Pollution Control Federation 42(5), 161-172

Dean, R. B., December 1968. "Ultimate Disposal of Waste Water Concentrates to the Environment," Environmental Science & Technology 2(12), 1079-1086.

Dean, R. B., March 1969. "Ultimate Disposal of Advanced Waste Treatment Residues," TAPPI 52(3), 457-461

Dean, R. B., June 1970. "Wastes from Membrane Processes," Environmental Science & Technology 4(6), 453.

Dean, R. B., 1969. "Ultimate Disposal of Waste Water: A Philosophical View," Water - 1969", Chemical Engineering Progress Symposium Series 65(97), 1-4.

Dean, R. B., September 1969. "Colloids Complicate Treatment Processes," Environmental Science & Technology, 3(9), 820-824.

Dean, R. B. and Bouthilet, R., July 1970. "Hydrolysis of Activated Sludge," to be presented at the Fifth International Conference on Water Pollution Research, San Francisco, California.

Dotson, G. K., Dean, R. B., Kenner, B. A., and Cooke, W. B., July 1970. "Land Spreading, A Conserving and Non-Polluting Method of Disposing of Oily Wastes," for presentation at the Fifth International Conference on Water Pollution Research, San Francisco, California.

Evans, J. O., February 1968. "They Spread 'Black Gold' on Their Fields," Pennsylvania Farmer 178(3), 36.

Evans, J. O., June 1969. "Ultimate Sludge Disposal and Soil Improvement," Water & Wastes Engineering 6(6), 45-48.

Farrell, J. E., Salotto, B. V., Dean, R. B., and Tolliver, W. E., 1968. "Removal of Phosphate from Wastewater by Aluminum Salts and Subsequent Aluminum Recovery," "Water - 1968", Chemical Engineering Progress Symposium Series 64(90), 232-239.

Mercer, B. W., Ames, L. L., Touhill, C. J., Van Slyke, W. J., and Dean, R. B., February 1970. "Ammonia Removal from Secondary Effluents by Selective Ion Exchange," J. Water Pollution Control Federation 42(2), R95-R107.

Mulbarger, M. C., Grossman, E., III, Dean, R. B., and Grant, O. L., December 1969. "Lime Clarification, Recovery, Reuse, and Sludge Dewatering Characteristics," J. Water Pollution Control Federation 41(12), 2070-2085.

TWRC-1 (14-12-52), October 1968. "Dilute Solution Reactions of the Nitrate Ion as Applied to Water Reclamation", Rocketdyne Division of North American Rockwell Corporation.

TWRC-5 (WPRD 26-01), March 1969. "Ammonia Removal from Agricultural Runoff and Secondary Effluents by Selected Ion Exchange", Battelle-Northwest.

TWRC-8 (14-12-413), March 1969. "Evaluation of Operating Parameters of Alumina Columns for the Selective Removal of Phosphorus from Wastewaters and the Ultimate Disposal of Phosphorus as Calcium Phosphate", Battelle-Northwest.

TWRC-10 (14-12-415), September, 1969. "Mathematical Model of Sewage Sludge Fluidized Bed Incinerator Capacities and Costs", General American Transportation Corporation.

WPRC 17070 DJW (14-12-495), November 1969. "State of the Art Review on Product Recovery", Resource Engineering Associates.

WP-20-4 (PH 86-66-32), May 1968. "A Study of Sludge Handling and Disposal", R. S. Burd, Dow Chemical Company.

14-12-171, January 1970. "Ultimate Disposal of Phosphate from Waste Water By Recovery as Fertilizer", W. R. Grace & Company, Dearborn Chemical Division.

ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

WASTEWATER RENOVATION AND REUSE

PPB 1708

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

1970 STATUS OF WASTEWATER RENOVATION AND REUSE

PPB - 1708

Reuse applications of wastewater include irrigation, formation of recreational lakes, industrial uses, groundwater recharge for a variety of reuses, and direct domestic reuse. Some of the applications can now be considered well established. Others are only beginning to be considered. There is, however, some activity in each area at this time.

IRRIGATION

Use of biologically treated wastewater for irrigation of non-edible crops and for parks and golf courses has become fairly widespread. With the technical feasibility of this application no longer in doubt, it should become more common in the future. Use of wastewater has the benefit of supplying significant amounts of plant nutrients, thus reducing fertilizer requirements. R&D Grant projects at Colorado Springs, Antelope Valley near Los Angeles, Irvine Ranch, California, and South Lake Tahoe, California include production of water for irrigation. An area in which wastewater is not used is for irrigation of food crops. Studies are needed to define better the water quality for this application.

RECREATIONAL LAKES

Filling of recreational lakes with renovated wastewater was begun at Santee, California in 1961. The success of that project has resulted in the establishment of several other lakes and many more are now being planned. To use wastewater for this application requires at least biological treatment and phosphorus removal. At Santee, phosphorus removal was first accomplished by passing biologically treated water through natural gravel beds. This method will probably be replaced by chemical precipitation using lime. Work at the site is being supported by an R&D Grant.

At Antelope Valley, California filling of a recreational lake with renovated wastewater was begun early this year. Treatment of the water at this location includes oxidation ponds and chemical clarification with alum. Development of the treatment system was partly supported by FWQA. The full scale project is being supported by an R&D Grant.

Another recreational lake project is that at South Tahoe. Indian Creek reservoir receives very high quality water from the Tahoe advanced waste treatment plant. The water is secondary effluent that has been clarified using lime and carbon treated.

The use of wastewater for recreational lakes can often be combined with irrigation. The lake merely serves as a reservoir for the irrigation water. The Tahoe site is an example of this dual purpose reuse.

INDUSTRIAL REUSE

Industrial reuse of wastewater represents a very large potential application. The largest single industrial use of water is for cooling water with an estimated annual volume of 57,000 billion gal. Two other important uses are for process water and boiler water feed.

The only major industrial reuse of wastewater up to this time has been for cooling water. For a number of years the Bethlehem Steel Company plant near Baltimore has been using secondary effluent for this purpose. Generally, it has been found that phosphorus removal is required for the water to be acceptable. At Baltimore the peculiar composition of the water allows phosphorus removal to occur during biological treatment. At other locations, such as at Las Vegas where the Nevada Power Company uses wastewater in their condensers, tertiary phosphorus removal is required. Lime treatment is used at the latter site.

FWQA did not support the early work on reusing wastewater for cooling purposes. Presently, however, Colorado Springs is receiving R&D Grant support for work in this area. A recently funded R&D Grant to Contra Costa County, California also includes reclamation of wastewater for cooling.

There is a need to investigate the use of wastewater for other industrial applications. The recent R&D Grant to Contra Costa County includes study of wastewater for boiler water feed. Work at that location may be extended to other industrial uses. More projects of this nature appear justified.

GROUNDWATER RECHARGE

An increasingly serious problem in water short areas is the lowering of the groundwater level. This occurs because water is pumped out but is not replaced. In coastal areas the result can be intrusion of seawater into aquifers making them unusable. In other locations brackish water may eventually replace the water removed.

It has been recognized that renovation of wastewater and recharge of this water may be a practical method for overcoming the problem. Recharge may be carried out by surface spreading of the water or injection into a well. In the Los Angeles area, surface spreading is being practiced. Recharge was begun in 1962 of the effluent from the Whittier Narrows Plant. This plant, operated by the Los Angeles County Sanitation Districts, produces a very high quality secondary effluent. Because of the porous nature of the spreading surface, no further treatment has been found necessary. Additional biological oxidation and nitrification of the effluent do take place during percolation through the soil. The quality of the renovated water is further improved by dilution with the natural groundwater.

In locations where the percolation rate is low or where spreading areas are not available, well injection would be necessary. Care must be taken in these cases to assure that the water is of proper quality to be compatible with the strata of the aquifer, i.e., will not form precipitates which clog the area around the well. Furthermore, the water must not contain suspended matter that will cause clogging. Orange County, California has experimented with injection of wastewater to decrease seawater intrusion. Treatment of the wastewater consisted of oxidation in a trickling filter followed by alum clarification. Nassau County, Long Island is studying injection for prevention of seawater intrusion and for other uses. This work is being supported by an R&D Grant. Treatment of the wastewater at this location consists of activated sludge, alum clarification, and granular carbon treatment. Nitrogen removal is also being considered.

DOMESTIC REUSE

Reuse of wastewater for domestic purposes involves both non-potable and potable applications. Non-potable use is not new and is no longer rare. Since 1925 treated wastewater has been used for flushing and other purposes at the Grand Canyon. Treatment consists of activated sludge, coal filtration, and chlorination. Similar systems are being used in other water-short resort areas. A biological treatment unit followed by membrane filtration is being tested at Pikes Peak. This work is being supported by an R&D Grant. It produces water of high clarity.

Instances of indirect potable use of renovated wastewater, such as occurs when a municipality practices water recharge, are increasing. In these cases there is usually a large amount of dilution water. The situation is similar to that occurring in many cities where river water containing effluents from cities upstream is used for the water supply.

The concept of direct reuse of wastewater for potable water has been discussed at length by many authorities in the water field for a decade or more. Essentially no direct reuse was actually carried out, however, until 1969 when a renovation plant at Windhoek, Southwest Africa began operation. For more than a year this plant has been supplying about one-third of the total water supply. The treatment system includes biological oxidation by trickling filter, further oxidation in maturation ponds, algae separation by alum flotation, foam fractionation for removal of foaming contaminants, filtration, carbon treatment for removal of remaining organic materials, and breakpoint chlorination for removal of any residual ammonia and for disinfection. This pioneering operation will have an important bearing on the growth of direct wastewater reuse. Other African communities are very much interested in similar projects. Continued success at this location should contribute significantly to the acceptance of this reuse concept.

OTHER SOURCES OF INFORMATION

Many articles have been written recently about reuse of wastewater. While these have dealt at length with the philosophy of reuse and possible treatment systems, they have not often reported actual reuse results. Much practical information on reuse has, undoubtedly, never been published. This information is of great importance to municipalities and to potential reuse customers in making decisions. There is a strong need to collect and analyze existing reuse results and to make them available in unified form.

A number of reuse articles have been collected in "Water Reuse", Chemical Engineering Progress Symposium Series No. 78, Vol. 63, 1967. Reading of this publication is recommended.

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
CINCINNATI, OHIO

CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

WASTE TREATMENT OPTIMIZATION

PPB 1709

Division of Process Research & Development
Federal Water Quality Administration
U. S. Department of the Interior

Waste Treatment Optimization
PPBS Category 1709

The four principal areas of activity for PPBS Category 1709, Waste Treatment Optimization are shown in Figure 1. A list of in-house reports completed is shown in Table I.

Design and performance technology is principally concerned with finding quantitative expressions for performance and cost of wastewater treatment processes as a function of the nature of the wastewater to be treated and the decision variables associated with the individual processes. These quantitative relationships take the form of mass balance relationships for all of the elementary chemical and physical constituents of contaminant present in the water, rate of reaction equations, and equations expressing the separation efficiency between liquid, particulate, and gaseous phases. Normally, a group of equations is required to express the performance of the process operating over the full gamut of operating modes and design decisions. This group of equations is often referred to as a mathematical model for the process. Mathematical models can be steady-state, quasi-steady-state, or time-dependent. Time-dependent models are of interest when the quality of the effluent stream from the process as a function of time is important or when the effectiveness of various kinds of control schemes is being considered. The computational procedure for solving all of the quantitative equations simultaneously is usually too laborious to be accomplished by hand calculation. The digital computer is, therefore, used in most cases. Expressing the models as computer programs has the additional advantage of packaging the information in succinct form readily usable by design engineers and planners.

A list of reports produced as a result of in-house activity is shown in Table I. A list of reports which have been completed as a result of contracting activity is shown in Table II. Only three of these contractor reports are now available for distribution. Other contracts in force will produce models for multiple hearth incineration of sewage sludges and microscreening. Contracts in force will also produce capital and operating and maintenance cost data for all of the conventional processes as well as a cost estimating guidelines manual and a staffing guidelines manual.

TREATMENT OPTIMIZATION RESEARCH PROGRAM

I. DESIGN AND PERFORMANCE PREDICTION TECHNOLOGY

1. Develop quasi-steady-state and time-dependent models for preliminary design and simulation

2. Validate design and simulation models by comparison with detailed measurements on operating plants

3. Develop quasi-steady-state models into a recognized standard of performance for use by governmental agencies for regulation and administration of grant-in-aid programs

II. OPERATION, MAINTENANCE, AND PLANT MANAGEMENT TECHNOLOGY

1. Plant performance standards and effluent quality control methods

2. Plant management, training, and staffing criteria and methods

3. State, County, or Regional systems for management and regulation

III. AUTOMATIC CONTROL FOR PLANTS

1. Study feasibility of proposed control loops with time-dependent models to solve transient problems

2. Study cost-effectiveness trade-off between automation and additional or better trained staff or better managerial surveillance

3. Demonstrate and evaluate control schemes on a loop-by-loop basis

4. Demonstrate interprocess control of complete plants

IV. COST-EFFECTIVENESS STUDIES

1. Selection of processes and design policies for least cost

2. Collection and organization of basic cost information

3. Develop recommended cost guidelines for cost estimation

FIGURE 1

TABLE I

PRINCIPAL REPORTS PRODUCED BY

TREATMENT OPTIMIZATION RESEARCH PROGRAM

1. Smith, Robert, "Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer", FWPCA Publication No. WP-20-9 (March, 1968).

2. Smith, Robert, "Cost of Conventional and Advanced Treatment of Wastewater", FWPCA Publication (July, 1968).

3. Smith, Robert, Eilers, Richard G. and Hall, Ella D., "Executive Digital Computer Program for Preliminary Design of Wastewater Treatment Systems", FWPCA Publication No. WP-20-14 (August, 1968).

4. Roesler, Joseph F. and Smith, Robert, "A Mathematical Model for a Trickling Filter", FWPCA Publication No. W69-2 (February, 1969).

5. Smith, Robert and McMichael, Walter F., "Cost and Performance Estimates for Tertiary Wastewater Treating Processes", FWPCA Publication (June, 1969), TWRC-9 Released January 15, 1970.

6. Roesler, Joseph F., "Preliminary Design of Surface Filtration Units (Microscreening)", FWPCA Publication (June, 1969).

7. Smith, Robert and Eilers, Richard G., "A Generalized Computer Model for Steady-State Performance of the Activated Sludge Process", FWPCA Publication (October, 1969).

8. Smith, Robert, "Factors to be Considered in Developing a Data Gathering and Analysis Plan Leading to Improvement of the Operational Effectiveness of Conventional Wastewater Treatment Plants", FWPCA Publication (December, 1969).

9. Roesler, J. F., Smith, R. and Eilers, R. G., "Mathematical Simulation of Ammonia Stripping Towers for Wastewater Treatment", In-House Report.

10. Smith, Robert and Eilers, Richard G., "Simulation of the Time-Dependent Performance of the Activated Sludge Process Using the Digital Computer", In-House Report 90% Complete.

11. Smith, Robert and Eilers, Richard G., "Cost to the Consumer of Collecting and Treating Wastewater in the United States", In-House Report (July, 1970).

TABLE II

1. "Cost of Wastewater Treatment Processes", TWRC-6, Dorr-Oliver, Inc.

2. "Mathematical Model of Tertiary Treatment by Lime Addition", TWRC-14, General American Research Division/General American Transportation Corp.

3. "Mathematical Model of Sewage Sludge Fluidized Bed Incinerator Capacities and Costs", TWRC-10, General American Research Division/General American Transportation Corp.

4. "Mathematical Model of the Electrodialysis Process", Process Research, Inc.

5. "A Mathematical Model of a Final Clarifier for the Activated Sludge Process", Rex Chainbelt Inc.

6. "Ammonia Stripping Mathematical Model for Wastewater Treatment", IIT Research Institute.

7. "Mathematical Model of Recalcination of Lime Sludge with Fluidized Bed Reactors", General American Research Division/General American Transportation Corp.

8. "Mathematical Model for Wastewater Treatment by Ion Exchange", IIT Research Institute.

9. "Methodology for Economic Evaluation of Municipal Water Supply/Wastewater Disposal Including Considerations of Seawater Distillation and Wastewater Renovation", Bechtel Corp.

10. "Mathematical Model for the Reverse Osmosis Process", Aerojet-General Corp.

As a result of the work reported in the first report in Table I, it was realized that a tool was needed which would allow the process designer to select the group of processes and the piping arrangement to be used and then calculate the performance and cost of the system as a whole. To meet this need an Executive Program was developed as described in the third report of Table I.

By iterative techniques the Executive Program calls each process subroutine in turn and recomputes all recycle streams until the correct solution for the system is found. Performance and cost for each process and for the system as a whole is printed. This program is simple in concept and requires a digital computer with a core memory of about 16K words.

Every quasi-steady-state model developed will ultimately be included in the Executive Program. A list of the individual processes to be included in the Executive Program are shown in Table III with the status of each model. No advanced processes are included in the Executive Program at the present time although several subroutines have been developed.

Preferred advanced or tertiary wastewater treatment systems are shown in the fifth report of Table I (TWRC-9). Estimated removal efficiency for all significant contaminants are given together with capital and operating and maintenance cost.

A generalized model for the activated sludge process has been developed and has been shown to fit data from a wide range of process modifications from the short detention time, low mixed liquor suspended solids, "modified process" to the "extended aeration process". This model is described in the seventh report listed in Table I. The most significant discovery associated with this work was that the maximum rate constant for synthesis is not a true constant but varies significantly with the loading on the process.

A time-dependent model for the activated sludge process has also been completed and the report on this model is about 90% complete. Three classes of active solids are considered; heterotrophs which convert biodegradable carbon to new cells, *Nitrosomonas* which converts ammonia nitrogen to new cells and nitrite, and *Nitrobacter* which converts nitrite to new cells and nitrate. This model has been used to investigate a number of schemes for automatic control of the activated sludge process. The most practical of the schemes involve sludge storage in the stabilization tank.

Another model for which a report has recently been completed is the model for ammonia stripping and cooling towers. The ammonia stripping portion of the program is embedded in the cooling tower calculation in order that the variation of Henry's Law constant with water temperature can be taken into account. The program can be used to calculate either ammonia stripping tower performance or cooling tower performance. Both crosscurrent and countercurrent towers are simulated. A numerical integration technique is used in which the tower is divided into cubical elements. Performance from various sources is being used to find the height of a transfer unit as a function of the type of packing and design decisions. Experimental data received from the Marley Co. for a particular packing have been analyzed to find the relationship between height of a transfer unit and the liquid and gas loading, (lb/hr/sq ft). The height of a transfer unit was found to depend on the ratio of gas to liquid loading as follows:

$$\text{Height of Transfer Unit, ft} = 4.1272\ (\text{Gas loading/liquid loading})^{1.257}$$

Various in-house and contract activities are underway to develop operation, maintenance, and plant management policies and methods which can be used to assure that a level of performance commensurate with the capability of the installed treatment works will be consistently achieved. The eighth report listed in Table I deals with these problems. Various contracts are either funded or being considered for funding.

The State of Minnesota has shown an interest in developing and demonstrating a computerized system for surveillance and regulation of treatment works within the State. The system would make use of all design and simulation relationships known to be valid for treatment processes. The physical characteristics of each particular treatment plant would be stored in the computer program. Design and simulation relationships would be used to compute the expected performance of each plant as a function of the measured influent stream. The transient nature of the feed stream and the stochastic aspects of performance relationships would be used to compute a range of expected performance. Monthly performance reports submitted by individual plants would be analyzed and evaluated in a matter of minutes. If deficiencies are detected some sort of remedial action could then be initiated.

Our approach to automatic control of plants is to study the cost and effectiveness of each individual control loop. Performance must be measured and documented with and without the control loop installed. Time-dependent mathematical models will be used to study the feasibility of untried control loops and to study the significance of time-dependent measurements made on individual processes. The tenth report in Table I deals with a time-dependent model for the activated sludge process.

Various cost-effectiveness studies are undertaken to show the cost contribution of various process system components and to study the cost-effectiveness trade-offs for competing process systems. The influence of size of community and the contribution of ancillary elements such as Customer Services and Accounting or General and Administrative Expense are studied to show the general cost perspective. A recent report shown as number eleven in Table I deals with these ancillary costs. Three selected figures from this seventy page report are shown in Figures 2, 3, and 4.

TABLE III

PROCESS SUBROUTINES TO BE INCLUDED IN THE EXECUTIVE PROGRAM

CONVENTIONAL PROCESSES

I. Physical Processes

1. Conveyance for Ultimate Disposal
   a. Pipelines
   b. Truck and Rail Transportation RFP (1/15/70)
   c. Ocean Outfalls

2. Sewage Pumping Facilities (In-house Task)

3. Pretreatment
   a. Bar Screens
   b. Comminution (In-house Task)
   c. Grit Removal

4. Primary Sedimentation (Completed)

5. Sludge Drying Beds (In-house Task)

6. Post and Pre Aeration (In-house Task)

II. Biological Processes

1. Activated Sludge Process (Completed)

2. Trickling Filter Process (Completed)

3. Waste Stabilization Ponds
   a. Aerated Lagoons
   b. Facultative Ponds RFP (1/15/70) + (In-house Task)
   c. Oxidation Ditches

4. Anaerobic Digestion (Completed)

5. Aerobic Digestion RFP (1/15/70)

III. Physical-Chemical Processes

1. Gravity Thickening of Organic Sludges RFP (1/15/70)

2. Centrifugation of Organic Sludges (Contract 515 Underway)

3. Flotation Thickening of Organic Sludges (Proposal Recommended)

4. Vacuum Filtration of Organic Sludges RFP (1/15/70)

5. Use of Chemicals to Promote Sedimentation (No Plans)

6. Elutriation of Organic Sludge (No Plans)

7. Multiple Hearth Incineration of Sludges (Contract 547 Underway)

8. Fluidized Bed Incineration of Organic Sludge (Completed)

9. Wet Oxidation of Organic Sludge (No Plans)

ADVANCED PROCESSES

I. Physical Processes

1. Cooling Towers (Completed)

2. Microscreening (Contract 819 Underway)

3. Rough Filtration of Secondary Effluent RFP (1/15/70)

4. Dual Media Filtration RFP (1/15/70)

II. Biological

1. Disinfection
   a. Chlorine
   b. Iodine (No Plans)
   c. Ozone

2. Denitrification in Columns RFP (1/15/70)

III. Physical-Chemical Processes

1. Lime Clarification (Completed)
   a. Recalcination of Lime Sludge (Fluidized Bed Complete)
   b. Recarbonation using CO_2 (In-house Task)

2. Ammonia Stripping Towers
   a. Countercurrent (Completed)
   b. Crosscurrent (Completed)
   c. Aeration (In-house Task)
   d. Biological Activity (In-house Task)
   e. Scaling (In-house Task)

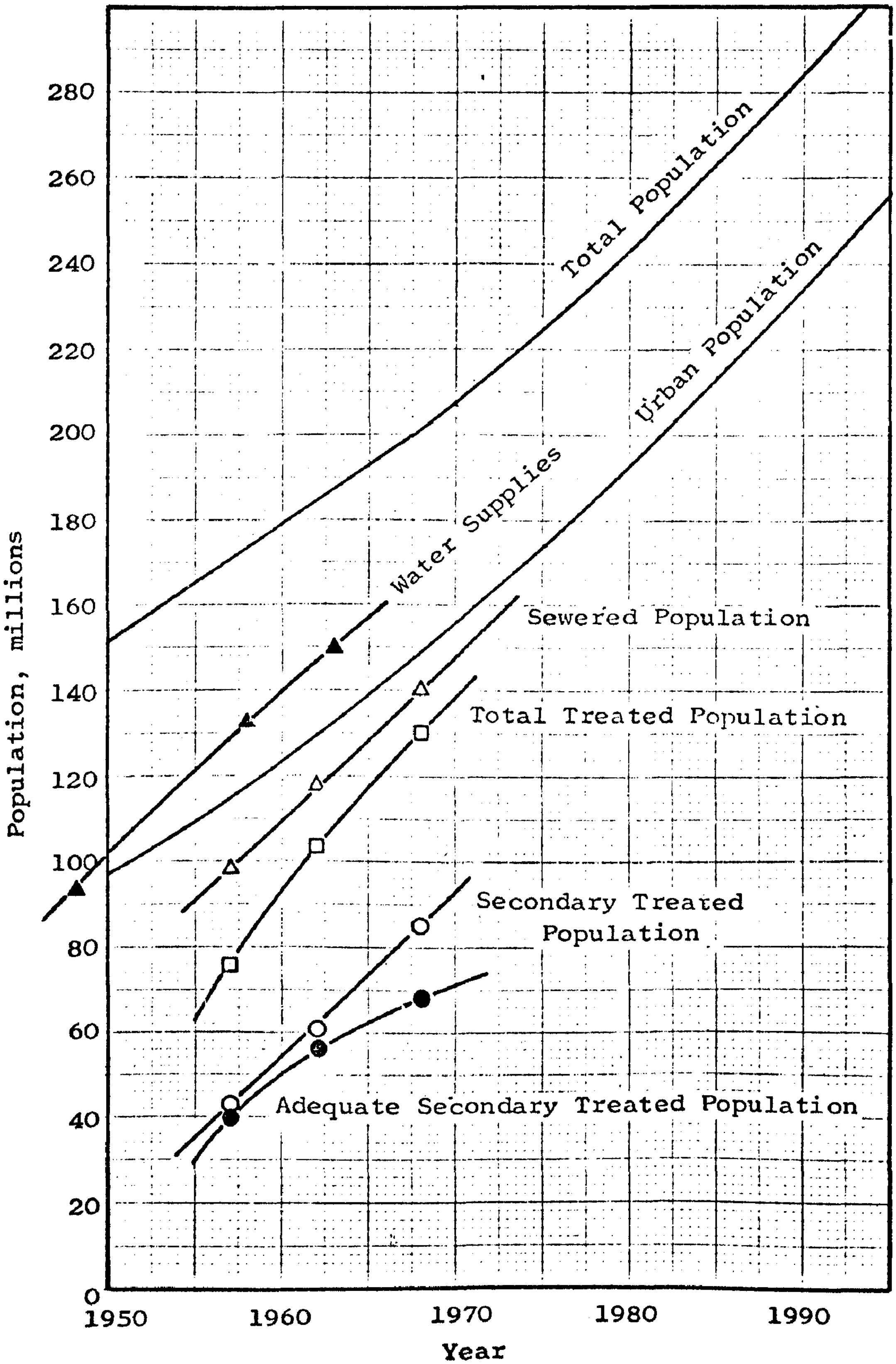
3. Granular Carbon Adsorption RFP (1/15/70)

4. Powdered Carbon Adsorption (No Plans)

5. Electrodialysis (Completed)

6. Reverse Osmosis (Completed)

7. Ion Exchange (Model Complete - In-house Task Req'd)



STATUS OF MUNICIPAL WASTEWATER TREATMENT FACILITIES
IN THE UNITED STATES

FIGURE 2

Type of Treatment

	Activated Sludge	Interceptors and Outfalls	Trickling Filter	Primary Sedimentation	Upgrading From Primary to Activated Sludge	Stabilization Ponds
Total Sewered Population	28.95	29.88	29.46	17.71	17.49	5.23
Activated Sludge and Extended Aeration	25.53	29.49				
Trickling Filter			45.14			
Primary Sedimentation				16.04	15.10	
Stabilization Ponds						21.42

NATIONWIDE AVERAGE CONSTRUCTION COST, DOLLARS PER CAPITA (1968 DOLLARS)

Source: cost data - R. L. Michel, Construction Grants and Engineering Branch, FWQA
population distributions - 1968 Inventory of Municipal Waste Facilities in the U. S.

FIGURE 3

FIGURE 4

TOTAL COST OF SEWAGE COLLECTION AND TREATMENT IN 1968 ON A CONTINUOUS CASH FLOW BASIS

1968 dollars/capita/year

Amortization Cost		
House Connection	$ 1.38	
Municipal Sewers	$ 8.64	
Interceptors and Outfalls	$ 2.46	
Treatment Plants	$ 2.83	
Total Amortization Cost	$15.31	
Current Expenses		
Municipal Sewer Maintenance		$0.86
Treatment Operation and Maintenance		$1.55
Customer Service and Accounting		$0.71
General and Administrative		$1.37
Total Current Expenses		$4.49
Total Cost of Municipal Collection and Treatment	$19.80	
Imputed Cost of Industrial Wastewater Treatment	$ 5.05	
Total	$24.85	

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ADVANCED WASTE TREATMENT RESEARCH LABORATORY
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CURRENT STATUS OF ADVANCED WASTE TREATMENT PROCESSES

July 1, 1970

SCIENTIFIC BASES OF WASTE TREATMENT PROCESSES

PPB 1700

Division of Process Research & Development
Federal Water Quality Administration
U.S. Department of the Interior

Status of Research on

Scientific Bases of Waste Treatment Processes

Waste treatment is a chemical process industry. Its function is to treat a starting material (sewage) of some chemical composition by optimum processes to convert it to another material of higher economic value/lower nuisance effect (treated effluent). Optimum processing requires adequate knowledge of the chemistry, physics, and biology of the raw material, treatment agents, and final product.

The major research effort has been on composition of wastes and its changes. Though sewage has been analyzed for nearly a century, our background knowledge is slight and expressed in quite general terms. An intensive analytical program has begun only now, both in-house and by contracts and grants. A first effort has been to determine how to sample effluents and transport samples to the laboratory. Freeze-concentration, though highly praised, is unsuitable. Vacuum concentration is the only practical means available so far. Though a systematic analytical program is evolving, we have leapfrogged to some more specific approaches. One of these, just begun by contract, consists of liquid chromatography of primary and secondary sewages, yielding fingerprint chromatograms. First trials show some 50 - 75 separated organic components, with conspicuous differences developing during biological treatment. Another of these leaps involves developing specific analyses for contaminants of special significance in sewage. Methods were developed for residual polymeric coagulant in treated sewage and for nitrilotriacetic acid in sewage receiving proposed new detergent formulations.

The molecular weight of sewage components is an important property for two reasons: (1) It controls the fractionation of organic components necessary to achieve ultimate isolation and identification of each, and (2) it has been claimed to be the controlling parameter in physical waste treatment processes. Molecular weight studies, both contract and in-house, are employing three techniques: membrane ultrafiltration, gel permeation chromatography, and osmometry. Comparison of the methods shows unexpected discrepancies in the apparent molecular weight values, also evidence of these fractions being complexed with metals. Early results indicate that the major part of secondary effluent organics average below 500 in molecular weight.

Of the treatment agents susceptible of elucidation by fundamental scientific research, activated carbon is the most important economically and also is most productive of useful information to guide processes, which have been largely empirical until now. The efficiency of activated carbon was found to depend on its basic characteristics, surface area, pore volume and dimensions, and surface functional groups, as predicted by theory. Other fundamental properties, not yet isolated, appear to be related to these. Apparently for the first time, meaningful information is being obtained about used and exhausted carbons, relating basic parameters to the performance of these carbons and their behavior on reactivation. In a different but related approach, thermal analysis has begun to be explored as a means of characterizing both the activated carbon and the adsorbed sewage components, as well as being used to predict reactivation behavior. These theoretical studies are aimed at establishing a sound scientific basis for carbon treatment processes now conducted with inadequate understanding.

One of the favorable characteristics of sewage, namely, that it supports well the bacterial population effecting biological treatment, is also a disadvantage, in that it makes sewage a hospitable medium for disease-producing bacteria. An intensive research program has been started to pass far beyond today's fixation on indicator organisms. Methods for assaying important pathogens in sewage -- Salmonella, Pseudomonas, Shigellae, among others -- are being developed and applied as criteria to measure the effectiveness of treatment processes in removing or destroying these organisms. Information about pathogens and indicator organisms has been assembled systematically to demonstrate the pollutional effect of primary effluent, even where BOD is not an issue.

If bacteria produce biological treatment, they can also interfere with other forms of treatment, especially physical methods, and with ultimate disposal of waste concentrates. Adverse bacterial effects have been characterized in carbon treatment (growth of pathogens) membrane processes (fouling organisms), and sludge disposal (persistence of bacteria).

The above research areas are fundamental and relatively long-term contributions to the efficiency of waste treatment processes. Since the bulk of treatment research, by other components, is immediate and necessarily empirical, this research must be guided by extensive analytical surveillance. To take advantage of the intrinsic efficiencies of specialization and centralization of advanced instruments, most of the required analyses are provided by a central analytical service laboratory, supplying about 3,000 analyses per month, distributed among some 35 methods. This support is also supplied to research contractors and grantees, including assistance in setting up and standardizing their laboratories.

To supply these services requires a constant program to select appropriate analytical methods, adapt them to labor-saving systems and instruments, develop new methods and systems for this purpose, and to shake down and calibrate these instrumental adaptations.

If the initial premise of this review is reprised -- that effective processes require adequate knowledge of the composition of starting and final materials and the way specific processes affect these compositions -- then it is apparent that the concept applies as well to full-scale treatment plants. The objective of automated control of treatment plants is accepted; such control can be accomplished only if equally automated methods of sensing composition changes can be developed. The automated instrumentation developed for volume work in the analytical laboratory is also the most promising approach to plant control instrumentation. A research effort in this direction, necessarily limited by meagre resources, has attained initial success in controlling a denitrification pilot plant by on-line analysis of nitrogen compounds and of denitrifying reagent feed. The extension of automated chemical instrumentation to full-scale treatment plant automation is a major program objective.

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